

INDIANA DEPARTMENT OF TRANSPORTATION

Post-construction Stormwater Management

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POST-CONSTRUCTION STORMWATER MANAGEMENT

1.0 INTRODUCTION

This document serves as the implementation guidance for meeting the requirements of the Indiana Department of Environmental Management (IDEM) National Pollution Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) General Permit and the Construction Stormwater General Permit (CSGP).

The United States Environmental Protection Agency (EPA) defines a municipal separate storm sewer system (MS4) as a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains), that is owned by a state, city, town, village, or other public entity that discharges to waters of the United States (40 CFR 122.26). INDOT has a National Pollution Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) General Permit from the Indiana Department of Environmental Management (IDEM) and must comply with EPA and IDEM requirements.

As of December 18, 2021, Indiana no longer administers the construction stormwater program under Indiana Administrative Code (327 IAC 15-5 or Rule 5). Permitting coverage is now issued under the Construction Stormwater General Permit (CSGP). The CSGP is a performance-based regulation designed to reduce pollutants that are associated with construction and/or land-disturbing activities.

The requirements of CSGP applies to all construction projects which include clearing, grading, excavation, and other land-disturbing activities that results in the disturbance of one (1) acre or more of total land area. If the land-disturbing activity results in the disturbance of less than one (1) acre of total land area but is part of a larger common plan of development or sale, the project must obtain permit coverage under the CSGP.

A minimum control measure (MCM) of the MS4 permit requires INDOT to develop post-construction stormwater management measures or best management practices (BMPs) for post-construction stormwater run-off control.

The term post-construction stormwater management measures will be used to differentiate these measures from temporary construction BMPs.

1.01 Applicability of the Construction Stormwater General Permit

IDEM's Construction Stormwater General Permit applies to all projects where the proposed land disturbance (in acres), including staging areas for construction, is one acre or more. To meet the requirements of the IDEM permits, post-construction stormwater management measures as defined in this document will be implemented on INDOT projects, as defined in Section 1.02.

Local Public Agency (LPA) projects will follow the local municipality's ordinances for post-construction measures, as applicable.

1.02 Post-construction Stormwater Management Measures Requirement

Post-construction stormwater management measures are required when the total disturbed area is 1 acre or more and there is 1 acre or more of new impervious surface or area. If both conditions are not met, post-construction stormwater management measures for water quality are not required. There may also be circumstances where installing structural measures may be infeasible (see Section 3.04).

For Local Public Agency (LPA) projects, the local MS4 requirements shall be followed. If there are no local MS4 requirements in place, IDEM's requirements shall be followed. Unless stormwater is being discharged into a county regulated drain, non-LPA INDOT projects will adhere to the requirements in this document and not the local or county MS4 requirements.

1.03 Target Pollutants

The U.S. EPA lists sediment as the most common pollutant in rivers, streams, lakes, and reservoirs. By targeting sediment removal in stormwater run-off, other types of pollutants will be removed as well. Sediment is the primary pollutant in stormwater run-off from the pavement on INDOT project sites once vegetation is properly established. Accordingly, the permanent stormwater quality control measures discussed in this document will target sediment removal. The required sediment removal rate as total suspended solids (TSS) for all qualifying INDOT projects is 80%.

If stormwater run-off discharges to an IDEM Total Maximum Daily Load (TMDL) Watershed or a stream on the 303(d) List of Impaired Waters, and there are pollutants of concern in INDOT's stormwater run-off, additional water quality treatment may be required if feasible. The Indiana Stormwater Quality Manual can be referenced for design guidance if additional treatment beyond TSS removal is required. The designer shall coordinate with INDOT prior to using the Indiana Stormwater Quality Manual for design guidance.

2.0 DEFINITIONS

A parenthetical number which follows a definition corresponds to the number of the cited reference shown in Section 11.0.

Best Management Practice (BMP). A method that has been determined to be the most effective and practical means of preventing or reducing non-point source pollution to help achieve water quality and quantity goals.

Biological Treatment. The removal of contaminants from stormwater using vegetation and/or microbiological activity by means of various physical and chemical processes.

Bypass System. A system of pipes or conduits that divert stormwater discharges from treatment facilities.

Design Storms. A theoretical storm used to analyze existing or new drainage systems often using a hyetograph or isohyetal map to show the time and spatial distribution of rainfall.

Detention. The interception of a volume of stormwater run-off to be temporarily stored in a constructed stormwater facility for gradual release to a receiving stream or system.

Dry Swale. A vegetated channel that conveys stormwater runoff and should completely drain between rainfall events.

Filtration. The process of removing contaminants from stormwater by allowing it to flow through vegetation or a bed of porous media such as sand, organic material, or soil.

Forebay. A pool of water upstream of another body of water or structural measure that acts as a settling basin for sediment in stormwater run-off.

Hydrograph Routing. A technique used to confirm that a detention facility provides adequate storage and will drain within the allotted timeframe.

Impervious Surface. Any land surface with a low or no capacity for soil infiltration, including but not limited to pavement (sidewalks, streets, parking areas, and driveways), packed gravel or soil, and rooftops. IDEM CSGP Appendix B.

Infeasible. Not technologically possible, or not economically practicable and achievable in light of best industry practices. IDEM CSGP Appendix B.

Infiltration. The process by which stormwater flows from the ground surface and percolates through the soil.

Level Spreader. A stormwater device that reduces the erosive energy of concentrated flows by distributing runoff as sheet flow to stabilized vegetative surfaces.

Non-structural BMP. Institutional and pollution-prevention practices designed to prevent or minimize pollutants from entering stormwater run-off and/or reduce the volume of stormwater requiring management.

Peak Flow Rate. The maximum flow rate for a given design storm at a specific location.

Retention. The interception of a volume of stormwater run-off to be permanently stored in a constructed stormwater facility.

Sedimentation. The process by which soil particles with a density greater than that of water settle to the bottom of a stormwater facility over time.

Soil Disturbance. The movement of soil that results from activities such as clearing, grading, excavation, and pavement removal.

Stormwater Management Measure. A practice or a combination of practices selected to improve the quality of run-off discharges, divert run-off, or mitigate the impacts related to quantity of run-off. IDEM CSGP Appendix B.

Stormwater Quality Measure. A practice, or a combination of practices, to control or minimize pollutants associated with stormwater run-off. IDEM CSGP Appendix B.

Structural Measures. Temporary or permanent facilities that are built to remove contaminants from stormwater run-off.

Total Maximum Daily Load. The calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant. A TMDL determines a pollutant reduction target and allocates load reductions necessary to the source(s) of the pollutant.

Treatment Train. Two or more structural measures placed in series (one downstream of another) to help achieve stormwater pollutant reduction goals.

Water Quality. The quality of water based on aquatic life criteria, biological criteria, human health criteria, and microbial/recreational criteria.

Water Quality Event. A rainfall event of one inch which produces the Water Quality Volume and Water Quality Treatment Rate used to design post-construction structural measures.

Water Quality Volume. The volume of run-off generated by the Water Quality Event for treatment in a post-construction structural measure.

The volume of run-off generated by one inch of rainfall on a site. IDEM CSGP Appendix B.

Water Quality Treatment Rate. The peak flow rate of stormwater run-off generated by the Water Quality Event for treatment in a flow-through post-construction structural measure.

Wet Swale. A vegetated channel that conveys stormwater runoff and that should maintain a permanent pool of water.

3.0 STRUCTURAL MEASURE SELECTION

3.01 Structural Measures

Although there are numerous structural post-construction measures available and in-use, INDOT has developed a list of preferred measures for selection, including the following:

- Dry Turf Grass Swale
- Dry Native Grass Swale
- Vegetated Turf Grass Filter Strip
- Vegetated Native Grass Filter Strip
- Dry Detention Pond
- Dry Detention Swale
- Wet Swale
- Wet Retention Pond
- Infiltration Swale
- Infiltration Basin
- Hydrodynamic Separator

Figure 3A includes INDOT's preferred structural measures along with their pollutant removal mechanism. Each measure is prioritized, with a value of "1" being most preferred and a value of "4" being least preferred. In some cases, measures in series will be required to achieve 80% TSS removal, often referred to as a treatment train.

3.02 Planning and Design-Related Minimum Measures

There are several design-related minimum measures that should be considered for INDOT projects. When possible, maximize vegetative conveyance of stormwater to reduce flow velocity, promote sedimentation, filtration, and uptake of pollutants; reduce run-off volumes through infiltration and evapotranspiration; and in some cases, provide wildlife habitat. This objective can be achieved by using swales for stormwater conveyance instead of storm sewers, for example. In some cases, it may be possible to avoid directly connected impervious areas (DCIAs) by allowing run-off to flow from the roadway through vegetation rather than directly into a storm sewer system. Preserving naturally vegetated areas and soil types helps to slow run-off, filter pollutants, and facilitate natural infiltration. It is also ideal to treat pollutants where they are generated or prevent their generation. However, site-specific constraints will affect which measures are appropriate for each project. Additionally, choosing the right measure(s) for each project requires sound engineering judgement and consideration of roadway layout, site specific conditions, environmental context, and hydrologic and hydraulic design. A flowchart can be seen in **Figure 3B** to help choose the most suitable measure for a given project.

3.02(01) Roadway Project Layout/Site-Specific Conditions

There are several site-specific factors that can limit post-construction measure selection.

- Available right-of-way can limit available space needed for some facilities such as dry detention and wet retention ponds. It is costly to acquire right-of-way in some locations, making the implementation of these measures infeasible.
- Steep slopes greater than 15% and other topographic constraints can also limit measure selection. Gentle slopes are preferred because they increase hydraulic retention time and sediment removal.
- Infiltration practices are discouraged in areas of karst topography, which are common in the southern part of the state.
- A high water-table can also impact the function of stormwater facilities designed to fully drain between rainfall events.
- In areas where the bedrock is close to the ground surface, excavation can be expensive.
- The contributing drainage area, both on-site and off-site, will affect measure selection. Large run-off volumes and high velocities can damage the stormwater facility and impact pollutant removal efficiency.
- Adjacent land-use can affect the off-site run-off draining to INDOT right-of way. Development can lead to increased flow rates and sediment loading.
- A measure should not encroach onto the roadway or an adjacent property.

- Underlying soils are important due to their ability to infiltrate run-off and support needed vegetation.
- A measure should not be placed in a jurisdictional stream.

3.02(02) Environmental Context

Measure selection and design is often influenced by pollutants that are reasonably expected to be present in stormwater run-off and the pollutants of concern in the receiving waterbody. Receiving streams on the current 303(d) List of Impaired Waters and TMDL Watersheds are to be considered by all Indiana MS4s. INDOT's temporary erosion and sediment control requirements remove TSS from INDOT's stormwater run-off during construction activities. For qualifying projects, this document provides design criteria to remove 80% of TSS from INDOT's stormwater run-off by installing permanent post-construction structural stormwater measures.

3.02(03) Hydrologic and Hydraulic Design Context

The permanent stormwater quality controls in this document are designed using the Water Quality Volume or the Water Quality Treatment Rate, which are both based on the Water Quality Event (1 inch of rainfall). The Water Quality Volume is the treatment volume required to remove a significant percentage of stormwater pollutant load. The Water Quality Treatment Rate is the peak rate of discharge for the water quality design storm needed for the sizing of flow-through measures.

It is important to note the Water Quality Volume and the Water Quality Treatment Rate are based on the total onsite contributing drainage area within INDOT right-of-way to the respective stormwater pollution prevention measure. Individual measures are sized for the total portion of the drainage area directed towards the measure. If off-site run-off is not separated from run-off generated within the right-of-way, the required measure size may be significantly increased. All stormwater from newly added impervious surfaces for qualifying projects (or equivalent impervious area) must pass through a structural post-construction stormwater measure. The design process for each measure using either the Water Quality Volume or the Water Quality Treatment Rate is described in detail in sections 4.0 through 10.0. The Water Quality Volume and Water Quality Treatment Rate can be determined using the following equations:

Water Quality Volume

$$WQ_v = \frac{(P \cdot R_v \cdot A)}{12} \quad \text{[Equation 3.1]}$$

Where:

WQ_v = water quality volume, acre-feet

P = rainfall, inches (use 1.0 inches)
 R_v = volumetric run-off coefficient
A = total proposed onsite drainage area, acres

And:

$$R_v = 0.05 + (0.009 * I) \quad \text{[Equation 3.2]}$$

Where:

I = percent new impervious cover, %

And:

$$I = \frac{P_{ia} - E_{ia}}{A} * 100 \quad \text{[Equation 3.3]}$$

Where:

P_{ia} = Proposed Onsite Impervious Area

E_{ia} = Existing Onsite Impervious Area

The Water Quality Volume in inches can be calculated with the equation below:

$$Q_{wv} = P * R_v \quad \text{[Equation 3.4]}$$

Where:

Q_{wv} = water quality volume, inches

P = rainfall, inches (use 1.0 inches)

R_v = volumetric run-off coefficient

Water Quality Treatment Rate

The following procedure will be used to estimate the Water Quality Treatment Rate (Q_{wq} , cfs) which is needed for flow-through measures.

1. Using Q_{wv} , a corresponding Water Quality Curve Number (CN_{wq}) is computed:

$$CN_{wq} = \frac{1000}{10 + (5 * P) + (10 * Q_{wv}) - (10 * [Q_{wv}^2 + 1.25 * Q_{wv} * P]^{1/2})} \quad \text{[Equation 3.5]}$$

Where:

Q_{wv} = water quality volume, inches

P = rainfall, inches (use 1.0 inches)

Alternatively, **Figure 3C** can be used to determine CN_{wq} . This graphical method is as acceptable as using Equation 3.5. Note, the CN_{wq} is not the same as a typical CN. The CN_{wq} is only used to determine the Water Quality Treatment Rate and should not be used in other applications.

2. Calculate the Time of Concentration (T_c) following the requirements in *Indiana Design Manual* (IDM) Chapter 202.
3. Using the CN_{wq} , T_c , and total onsite area draining to the measure, compute the Water Quality Treatment Rate (Q_{wq}) in cfs following hydrograph-oriented procedures approved in the IDM. Use NRCS Type II rainfall distribution and a rainfall depth of 1.0 inches. Software programs that use TR-55 and TR-20 methodologies are acceptable.

TSS Removal Rates for Structural Measures in Series

If 80% TSS removal cannot be achieved using one measure, multiple measures placed in series may be required. The following equation shall be used to calculate the TSS removal rate for measures in series.

$$R_t = R_1 + R_2 - \frac{R_1 * R_2}{100} \quad \text{[Equation 3.6]}$$

Where:

R_t = Total TSS Removal Rate, %

R_1 = TSS Removal Rate of the First or Upstream measure, %

R_2 = TSS Removal Rate of the Second or Downstream measure, %

TSS Removal Rates for Projects with Multiple Discharge Points

If there are multiple discharge points from the project site with corresponding sub-areas, a weighted average of the TSS removal rates may be used. However, the discharge points must ultimately flow to the same receiving stream.

$$R_{avg} = \frac{(A_1 * R_1) + (A_2 * R_2)}{A_1 + A_2} \quad \text{[Equation 3.7]}$$

Where:

R_{avg} = Average TSS Removal Rate, %

R_1 = TSS Removal Rate of the First Onsite Area, %

R_2 = TSS Removal Rate of the Second Onsite Area, %

A_1 = First Onsite Area, acres

A_2 = Second Onsite Area, acres

3.03 Construction, Inspection and Maintenance Considerations

Although proper design is critical for structural measures to function correctly, proper construction and maintenance are equally important. The measure designer should consider location-specific constraints and constructability, in addition to other design requirements provided in this document, because each measure will present unique construction and maintenance issues.

3.03(01) Construction

When designing a structural measure, the engineer should choose a layout that facilitates equipment access to ensure ease of constructability and reduce construction costs. The construction plans should be detailed and clearly address any constraints. Critical design criteria should be clearly documented in the construction plans and critical dimensions should be discussed at preconstruction meetings. The time of year the measure will be constructed should be considered due to vegetation establishment needs. Through adequate planning and coordination, many potential problems can be avoided.

3.03(02) Inspection and Maintenance

All post-construction structural measures will be put on an inspection schedule and maintenance activities will be performed as needed. It is important for the measure designer to understand the type of maintenance activities required for the measure and provide adequate permanent drainage easement or right-of-way around the measure for these activities. Safety should always be considered.

Each permanent structural measure will be given an asset identification number and will require an inspection and maintenance plan. Templates in editable format are provided on the [INDOT Stormwater](#) webpage. The Engineer of Record is required to fill out the appropriate template and provide it along with the other submittal documents.

3.04 Infeasibility Determination

In some circumstances, it may not be feasible to construct one or more post-construction structural measures in the project area. It may be possible to install the post-construction structural measures outside of the project area but within the same watershed to satisfy the requirement. Prior coordination with the INDOT Environmental Services Division will be necessary.

3.04(01) Infeasibility Criteria

Receiving streams on the current 303(d) List of Impaired Waters and TMDL Watersheds are to be considered by all Indiana MS4s. However, the primary pollutants coming from INDOT right-of-way are sediment and chlorides.

It may be economically infeasible to construct measures to treat new pavement in some areas due to limited available right-of-way, utility relocations, or limited construction material availability. In some areas, topography constraints can make construction and maintenance activities infeasible. Additionally, large amounts of offsite flow can make installing structural measures infeasible. If the designer thinks constructing structural measures as part of a project might be infeasible, they should coordinate with INDOT Environmental Services Division and other INDOT staff as needed.

3.04(02) Infeasibility Documentation

If it is determined that it will be infeasible to treat INDOT's stormwater run-off to remove 80% TSS, infeasibility documentation must be submitted. If it is only feasible to remove a smaller percentage of TSS from the run-off, infeasibility documentation will also be required. The documentation will include the following:

- Description of project purpose, with exhibits showing location, outlets, and existing and proposed features and topography
- Calculations of Water Quality Volume and/or Water Quality Treatment Rate
- Reason(s) constructing post-construction structural measures is not feasible
- Construction cost estimate for measures if cost is a factor
- Proposed plans
- If applicable, percentage of TSS that is feasible to remove from run-off
- Potential alternatives to treat existing impervious areas of equivalent size in another location instead of proposed added pavement

4.0 DRY TURF GRASS AND NATIVE GRASS SWALES

4.01 Dry Swale Overview

A dry swale used for water quality treatment can be natural or engineered and is designed to convey and treat run-off from the roadway. A dry swale will convey flow during wet weather events but should completely dry out between events. Dry swales are often most preferred because they generally take the least amount of right-of-way to implement compared to other green infrastructure post-construction stormwater measures. Dry swales can be planted with turf grass

or native vegetation and are referred to as turf grass swales and native grass swales in this chapter. The only difference between the two dry swale types are the plantings. **Figures 4A** and **4B** depict a turf grass swale and a native grass swale, respectively.

Swales typically have either a trapezoidal or V-shaped cross section. There should not be an underdrain. The objective of a dry swale is to decrease the velocity of flow to promote sedimentation and physical filtration of solids and biological uptake from the grass. In steep terrain, a modified check dam with a trapezoidal opening is sometimes needed to slow the velocity of flow within a dry swale.

4.02 Dry Swale Applications

Dry turf grass and native grass swales can be ideal for linear highway, interchange, and facility applications and are best suited for small drainage areas. Water depth and velocity are important factors when implementing swales in larger drainage areas because as the flow deepens and the velocity increases, the swales effectiveness is thereby reduced. Erosion within the swale can also become an issue. However, grass swales can be integrated into treatment trains when needed.

4.03 Dry Swale Advantages and Limitations

The biggest advantage to choosing dry swales for water quality treatment is the relatively low cost. Right-of-way requirements are lower for swales compared to some other green infrastructure measures and construction costs are also typically less. Additionally, many INDOT roadways already have dry grass swales within the right-of-way.

A disadvantage is that before vegetation is established, significant erosion can occur, so a temporary erosion-resistant lining may be required during construction. It is extremely important that adequate vegetation is established in the swale otherwise TSS will not be removed. If the contributing drainage area has a high sediment loading, the extra sediment may have to be removed to maintain available flow area. Additionally, rills may form if the bottom width of the swale is greater than 10 feet.

4.04 Dry Swale Design

Flow rate is the critical hydraulic parameter for swale design. The swale should be designed to meet requirements in IDM Chapter 203 in addition to the requirements in this chapter. After the Water Quality Treatment Rate (Q_{wq}) and other applicable flow rates are determined, water quality swale design is primarily composed of determining the swale geometry and swale length. Manning's Equation should be used to determine the velocity, and it is recommended to use a Manning's calculator or modeling program because this is often an iterative process.

4.04(01) Dry Swale Geometry

Side slopes must be 3:1 or flatter for maintenance purposes. The dry swale geometry should be determined using Manning's Equation and the Water Quality Treatment Rate (Q_{wq}) in addition to requirements in IDM Chapter 203 (that pertain to stormwater conveyance). When designing a dry turf grass or native grass swale to meet INDOT water quality requirements, the depth of flow must be at or below the height of the grass in the bottom of the swale during the Water Quality Event, and a Manning's n value of 0.15 is used. The maximum allowable depth of flow in the swale during the water quality event is based on the type of grass planted in the swale, as listed in **Figure 4C**. When higher flow rates are analyzed to meet requirements in IDM Chapter 203, Manning's n values listed in Chapter 203 shall be used.

The velocity in the swale during the Water Quality Event (v_{wq}) should not be greater than 4 feet per second (fps). If the water depth in the swale during the water quality event is higher than the values listed in **Figure 4C**, the swale geometry shall be adjusted. Although the depth of flow in the swale cannot be higher than the height of the grass during the Water Quality Event, it can be deeper during higher flows.

4.04(02) Dry Swale Length

Removal of sediment by settling is dependent on the hydraulic residence time in the swale. The hydraulic residence time (T_{ahr}) is determined by the following equation:

Hydraulic Residence Time

$$T_{ahr} = \frac{(L_{swale}/v_{wq})}{60} \quad \text{[Equation 4.1]}$$

Where:

T_{ahr} = hydraulic residence time, minutes

L_{swale} = length of swale, feet

v_{wq} = peak flow velocity at water quality event, ft/s

The swale length should be sized so that the hydraulic residence time in the swale is greater than or equal to 9 minutes to achieve 80% sediment removal. See **Figure 4D** for TSS removal rates achieved at various hydraulic residence times. These calculations can be performed on an existing swale to determine if it can be used to meet the requirements in this chapter.

4.04(03) Dry Swale with Check Dams

In areas with steep terrain, permanent modified check dams may need to be constructed to reduce velocity and increase hydraulic residence time. A minimum longitudinal slope of 1 percent is required if check dams are to be installed. The foreslope and backslope of the check dams will be 2:1 or flatter with a 1.5-foot minimum top width. These check dams will have a trapezoidal opening in the center that will allow water to flow through the structure. The trapezoidal opening must be a minimum of 1.5 feet wide at the bottom with 2:1 or flatter side slopes. Revetment riprap will be used, keyed in 1.5 feet below the flowline. The check dam will be completely made of up of stone and is designed to fully drain. **Figure 4E** depicts a dry swale with a check dam.

If check dams are used, the depth of flow in the swale during the Water Quality Event must be below the height of the vegetation. Therefore, turf grass will not be appropriate when check dams are needed because it will not be possible to construct a check dam with the height limited to 6 inches. The maximum allowable check dam height is 2 feet. During larger rainfall events, flow can overtop the check dam.

If check dams are installed for peak flow mitigation, the procedures outlined in IDM Chapter 203 shall be followed. Regardless of the purpose for check dam installation, roadway serviceability requirements shall be met.

The swale geometry must be checked to ensure the desired TSS removal is achieved using the following procedure:

1. Use the continuity equation, also known as the transport equation:

$$v_{wq1} = \frac{Q_{wq}}{A_{wq1}} \quad \text{[Equation 4.2]}$$

Where:

A_{wq1} = cross-sectional flow area in swale during water quality event just upstream of the check dam, ft²
 V_{wq1} = velocity in swale during water quality event just upstream of the check dam, ft/s
 Q_{wq} = water quality flow rate, cfs

2. Determine the check dam geometry.
3. Assume the geometry of the trapezoidal shaped opening in the check dam. The bottom of the opening is at the flowline elevation.
4. Calculate the water surface elevation through the check dam opening using Manning's Equation and the Water Quality Treatment Rate.

5. Assume the water surface elevation in the swale directly upstream of the check dam is the same as the water surface elevation through the trapezoidal check dam opening.
6. Assume a bottom width and side slopes for the swale upstream of the check dam.
7. Calculate the cross-sectional flow area (A_{wq1}) of the swale using the depth of water in the swale determined in step 4.
8. With A_{wq1} and Q_{wq} now known, solve for v_{wq1} using Equation 4.2.
9. Determine v_{wq2} for the portion of the swale not affected by the check dam using Manning's equation, Q_{wq} , and A_{wq2} .
10. Average v_{wq1} and v_{wq2} to obtain v_{wq} .
11. Determine the applicable length of the swale (L_{swale}) affected by the check dam (see Figure 4E).
12. Using v_{wq} and L_{swale} , calculate T_{ahr} using Equation 4.1.

4.04(04) Offsite Flow Entering Swale

In some cases, there will be off-site flow coming into the water quality swale. If the off-site flow cannot be bypassed around the water quality swale, then the offsite flow must be accounted for to ensure the depth of water in the swale during the Water Quality Event is not above the height of the vegetation. To account for off-site flow into the swale, assume the following:

- T_c will be derived following typical TR-55 and IDM Chapter 202 procedures.
- CN will be derived using the same process as the CN_{wq} , using percent impervious area instead of percent new impervious area.
- Calculate flow using NRCS Type II rainfall distribution and a rainfall depth of 1.0 inches
- Two basins are then required, one for the onsite area and another for the offsite area.
- The two basins should be analyzed together with the same outlet (the dry swale) to determine the peak flow to the swale during the Water Quality Event.

4.04(05) Dry Swale Seeding

Dry swales with a longitudinal slope of less than 1% can be planted with seed. Dry swales with longitudinal slopes greater than 1% or less than 3% will be sod-lined or check dams may need to be installed. Dry swales with longitudinal slopes greater than 3% may require check dams due to the need for plant establishment.

Turf grass swales should be planted with Seed Mixture R in rural areas and Seed Mixture U in urban areas, following INDOT's Seed Mixtures and Seed Requirements Standard Specifications. Native grass swales should be planted with the Native Grass Mix provided in the Appendix. For both types of swales, a plant growth layer, following INDOT Standard Specifications, should be included in the design.

5.0 VEGETATED FILTER STRIP

5.01 Vegetated Filter Strip Overview

A filter strip is a vegetated, uniformly graded area that receives sheet flow and is typically located between a pollutant source and either another measure or a waterbody. These strips generally have mild slopes and can be planted with turf grass or native grasses or can use existing vegetation including trees and shrubs. A vegetated filter strip is depicted in **Figure 5A**.

The effectiveness of a vegetated filter strip for TSS removal is controlled by the underlying soil, the type of vegetation, and the cross-sectional slope of the strip. Stormwater run-off sheet-flows through the vegetation which promotes sedimentation, filtration, adsorption, infiltration, biological uptake, and microbial activity.

5.02 Vegetated Filter Strip Applications

Vegetated filter strips are ideal for linear projects such as roadways without curb and gutter. There is often adequate space for a filter strip between the edge of the roadway pavement and the roadside ditch. If flow is concentrated, a filter strip alone is not appropriate. However, a level spreader can be installed to redistribute flow in some cases.

5.03 Vegetated Filter Strip Advantages and Limitations

Vegetated filter strips have a relatively low cost compared to other measures if adequate space is available. They also require relatively low maintenance once vegetation is established.

A vegetated filter strip is only effective if the run-off entering and flowing through the strip is sheet flow. Because the flow through the filter strip must be sheet flow, the area draining to the strip must be uniformly graded, or in the case of existing areas, the surface must have features that pond or disperse the run-off before it enters the strip. Additionally, larger drainage areas cannot be treated with a vegetated filter strip. It is also extremely important that vegetation be well established for a filter strip to remove TSS from run-off.

5.04 Vegetated Filter Strip Design

Flow must enter the vegetated filter strip as sheet flow and remain as sheet flow until it leaves the strip. The length of the filter strip is measured between the edge of the pavement, or area sheet flow is received, to the receiving stream, as shown in **Figure 5A**. The length of the drainage area contributing to sheet flow to the filter strip cannot be more than 100 feet for impervious surfaces and 150 feet for pervious surfaces. The longitudinal slope is calculated along the length of the

filter strip. The Hydrologic Soil Group (HSG) of the underlying soil beneath the filter strip should be obtained using information available through Natural Resources Conservation Service (NRCS), soil testing, or another resource if available.

To determine the percent TSS removal for a vegetated filter strip, **Figures 5B to 5E** will be used. The filter strip longitudinal percent slope is shown on the X axis of the graphs and the filter strip length, in feet, is shown on the Y axis of the graphs. The percent TSS removal for strips planted with turf grass, native grasses, and existing woods can then be determined based on the HSG of the existing underlying soil. Although existing trees can be used, the intent is not to plant trees on these filter strips due to proximity to the roadway.

5.05 Vegetated Filter Strip Seeding

Vegetated filter strips can be planted with Seed Mixture R in rural areas and Seed Mixture U in urban areas, following INDOT's Seed Mixtures and Seed Requirements Standard Specifications. If the vegetated filter strip is designed to include native grasses, use the Native Grass Seed Mix provided in the Appendix. For both types of vegetation, a plant growth layer, following INDOT Standard Specifications, should be included in the design.

6.0 DRY DETENTION

6.01 Dry Detention Overview

A dry detention measure is a pond or swale that captures and temporarily detains stormwater runoff for a specific duration. Dry detention measures can serve as peak flow mitigation devices while also providing water quality benefits by promoting the settlement of suspended pollutants. Because traditional dry detention measures are not meant to have a permanent pool of water, the entire pond or swale must be designed to drain within 72 hours. A dry detention measure is depicted in **Figure 6A**. Additional information about dry detention measures is provided in IDM Chapter 203.

6.02 Dry Detention Applications

A dry detention measure may not be the ideal measure to choose to meet the requirements if there is not already a dry detention measure needed for peak flow mitigation. However, if an INDOT project requires peak flow mitigation based on design criteria in IDM Chapter 203, the dry detention measure should also be accounted for to help meet the requirements of this document.

6.03 Dry Detention Advantages and Limitations

Because stormwater is detained within a dry detention measure, erosive velocities downstream may be reduced, which also helps reduce TSS and other negative hydrologic impacts in the receiving waterbody. Dry detention measures can be implemented in series with other structural measures such as filter strips and swales.

In some cases, inline ditch detention is used, requiring less right-of-way. However, dry detention ponds often require a relatively large footprint to meet peak flow mitigation requirements. They also require more frequent inspections than some other structural measures because they require inspection after large rainfall events, primarily to ensure the outlet structures are not clogged with trash or debris.

6.04 Dry Detention Design

When using a dry detention measure for water quality treatment, the minimum flow length-to-width ratio is 3:1 to prevent short-circuiting and promote filtration and sedimentation. For dry detention ponds, if it is not possible to achieve a minimum length-to-width ratio of 3:1, baffles can be installed to lengthen the flow path through the pond, or a meandering pilot channel can be constructed. Detention ponds with a higher length-to-width ratios will resemble a swale, and some designers may refer to these measures as ditch detention. A dry forebay is recommended but not required.

The dry detention measure should detain the Water Quality Volume and release it over a time of 24 hours or more to achieve 80% TSS removal. A multi-stage outlet structure may be needed. The smallest allowable outlet pipe diameter is 4 inches due to clogging concerns. If the outlet pipe has a diameter of less than 6 inches, a reducer is required. If the outlet pipe diameter is 10 inches or less, 50 feet of perforated pipe (one nominal size larger than the outlet pipe diameter) shall be installed in a stone trench and connected to the outlet structure. The stone trench width will include a minimum of one foot on each side of the perforated pipe and 1:1 side slopes. The depth should include a minimum of 6 inches (12 inches preferred) above the perforated pipe and 6 inches below it. Clean washed #2 stone will be used in the trench, with geotextiles lining the bottom and sides. Soil will not be placed on top of the stone trench. The stone trench and perforated pipe length minimum is 50 feet. For some dry detention measures with larger contributing drainage areas, a longer stone trench and perforated pipe may be required.

The detention measure will be modeled with the small outlet pipe used to detain the water quality volume, another opening for the design storm (if applicable), and the 100-year opening. The perforated pipe underdrain system does not need to be modeled. A software program that allows

for multiple pond outlets will be required. **Figure 6B** shows a dry detention pond outlet structure with a perforated pipe underdrain.

Alternatively, the dry detention measure could be analyzed as a swale using the Water Quality Treatment Rate. If this approach is chosen, a meandering pilot channel may be required, and the depth of flow during the Water Quality Event must be at or below the height of the vegetation in the pilot channel. See Section 4.04.

6.05 Dry Detention Seeding

Dry detention measures will be planted with Seed Mixture R in rural areas and Seed Mixture U in urban areas, following INDOT's Seed Mixtures and Seed Requirements Standard Specifications. A plant growth layer, following INDOT Standard Specifications, should be included in the design.

7.0 WET SWALE

7.01 Wet Swale Overview

Like a dry swale, a wet swale used for water quality treatment can be natural or engineered and is designed to convey and treat run-off from the roadway. The objective of a wet swale is to permanently retain the Water Quality Volume to allow sediment particles to settle out of the stormwater run-off. A check dam without an outlet structure is typically required. Larger flows can overtop the check dam and convey to an offsite outlet. **Figure 7A** depicts a wet swale.

Swales typically have either a trapezoidal or V-shaped cross section. There should be no underdrain. A wet swale needs to have a high water-table or poorly drained soils to properly retain water.

7.02 Wet Swale Applications

Wet swales can be used to treat stormwater run-off when the water table is high or when there are poorly drained existing underlying soils. It might be desirable to choose a wet swale over a dry swale if only a relatively short swale length is available or if it is not possible for the swale to fully drain between rainfall events.

7.03 Wet Swale Advantages and Limitations

One advantage of wet swales is they can provide aquatic wildlife habitat. Additionally, wet swales are known to treat other pollutants that can come from offsite such as nutrients, metals, and pathogens through biological removal.

Unfortunately, there are several common problems associated with wet swale application. Vegetation establishment can be difficult due to the need for emergent plant life, and emergent plant life requires proper pH levels in the swale to thrive. The wet swale water can become stagnated, causing unpleasant odors. Wet swales also tend to attract nuisance insects, resulting in mosquitoes breeding and ant mounds. For this reason, it is often not desirable to construct a wet swale in a residential or commercial area unless the swale will be properly maintained.

7.04 Wet Swale Design

Wet swale design must meet hydraulic capacity and serviceability requirements in IDM Chapter 203 in addition to the requirements in this document. Side slopes must be 3:1 or flatter unless an existing wet swale is being used. The wet swale must permanently retain the Water Quality Volume and the permanent pool volume should be larger than the WQ_v . In some cases, such as if the wet swale measure drains to another waterbody and will remain wet due to the high-water table, a check dam may not be required.

If a check dam is required, typically it should not have an outlet pipe. In some cases, such as when the wet swale receives larger offsite flows, the integrity of the check dam could be compromised. If larger flows are entering the wet swale, the check dam should include a riser pipe connected to an outlet pipe, with the riser pipe set at the 100-year water surface elevation (or lower), and the top of the berm 1 foot above that (like a wet retention pond berm). Alternatively, the check dam can include an overflow weir with capacity for the 100-year event. In either situation, the structural integrity of the berm must be considered by the designer.

7.05 Wet Swale Seeding

In areas above the permanent pool elevation, wet swales should be planted with Seed Mixture R in rural areas and Seed Mixture U in urban areas, following INDOT's Seed Mixtures and Seed Requirements Standard Specification (if turf grass is desired). Alternatively, native grass can be planted with the Native Grass Seed Mix provided in the Appendix. Below the permanent pool elevation, the Emergent Plant Seed Mixture provided in the Appendix should be used. A plant growth layer, following INDOT Standard Specifications, should be included in the design.

8.0 WET RETENTION POND

8.01 Wet Retention Pond Overview

A wet retention pond is a detention basin that maintains a permanent pool of water. Wet retention ponds can serve as peak flow mitigation devices while also providing water quality benefits by promoting the settlement of TSS and biological uptake of suspended pollutants. Additional storage

is provided in the pond above the permanent pool of water. **Figure 8A** depicts a wet retention pond.

8.02 Wet Retention Pond Applications

Although wet retention ponds can be used for linear highway projects, they are more typically seen in residential and commercial areas where they can add to property value and provide recreational activities. A wet retention pond may be best suited to sites where there is adequate space in a low-lying area with a high water-table. Wet retention ponds will rarely be used for INDOT projects.

8.03 Wet Retention Pond Advantages and Limitations

In addition to removing TSS from stormwater run-off by allowing particles to settle out, wet retention ponds reduce velocities in the downstream receiving water body, which helps prevent erosion and other negative hydrologic impacts. The plants, algae, and bacteria in wet retention ponds help remove other pollutants that can come from offsite such as nutrients, metals, and pathogens. Wet retention ponds also provide aquatic wildlife habitat.

Wet retention ponds are not recommended for linear roadway projects due to the limited available space and maintenance requirements. Excess nutrients can result in eutrophication, so regular chemical treatment or aeration is required.

8.04 Wet Retention Pond Design

For 80% TSS removal, the permanent pool volume within the wet pond must be larger than the WQ_v . The pond can be designed to permanently detain a larger volume or temporarily store a larger volume for peak flow mitigation. Extended detention can be provided by slowly releasing the volume of water above the permanent pool elevation. An outlet structure and emergency overflow structure are required as described in IDM Chapter 203. Erosion protection must be installed downstream of the outlet structure.

8.05 Wet Retention Pond Seeding

Wet Retention Ponds will be planted with Seed Mixture R in rural areas and Seed Mixture U in urban areas above the permanent pool elevation, following INDOT's Seed Mixtures and Seed Requirements Standard Specifications. Alternatively, native grass can be planted above the permanent pool elevation with the Native Grass Seed Mix provided in the Appendix. A plant growth layer, following INDOT Standard Specifications, should be included in the design in planted areas. Plantings are not required below the permanent pool elevation.

9.0 INFILTRATION

9.01 Infiltration Overview

An infiltration feature is a structural measure that collects run-off and allows it to drain through the underlying soil. Infiltration practices can be used to meet both water quantity and water quality goals when proper site selection, design, construction, and maintenance processes are followed. When designing infiltration facilities, design criteria in IDM Chapter 203 shall also be adhered to.

Infiltration practices are used in various post-construction stormwater measures, including bioretention basins, infiltration trenches, sand filters, infiltration swales, and infiltration basins. For INDOT projects, the only acceptable infiltration features are infiltration basins or infiltration swales. In some cases, infiltration features will also be used to meet peak flow mitigation goals, or when a suitable site outlet does not exist. An infiltration basin is depicted in Figure 9A and an infiltration swale is depicted in Figure 9B.

9.02 Infiltration Applications

Infiltration practices may only be used when the existing underlying soils are composed of loam, sandy loam, loamy sand, and sand. Engineered soil media will not typically be used in infiltration basins and swales for INDOT projects. Instead, the existing underlying soil should be capable of achieving proper infiltration. Infiltration features cannot be installed in areas with a high water-table. It is preferred to have a 4-foot separation between the infiltration feature bottom and the seasonal high water-table; however, a 2-foot separation will be allowed.

9.03 Infiltration Advantages and Limitations

Because all the water quality volume is infiltrated into the soil, infiltration basins promote groundwater recharge and are considered to have a high pollutant removal capacity. Not only do infiltration features remove TSS, they also prevent dissolved pollutants from directly entering the receiving stream. As the stormwater percolates through the underlying soil, physical, chemical, and biological processes remove a majority of contaminants.

In Indiana, most areas do not have the proper underlying soil types to use infiltration. Infiltration practices have been historically known for high rates of failure due to clogging caused by high sediment loading, poor design, improper construction, and neglected maintenance. Infiltration basins and swales should not be used in areas of karst topography or well-head protection areas.

9.04 Infiltration Design

If the infiltration feature is also being used as a peak flow mitigation facility, all requirements in Chapter 203 must be adhered to. Although not required, pretreatment by means of a vegetated filter strip or dry sediment forebay is recommended. Otherwise, the infiltration feature will likely require more maintenance to address clogging.

Soil testing is required per the guidelines provided in IDM Chapter 203 for infiltration basins and swales. To demonstrate an infiltration basin or swale will reduce the TSS in run-off by 80%, all the Water Quality Volume must be infiltrated. The basin or swale must also provide enough above ground storage to allow water to pond while it is being infiltrated.

If the infiltration feature is also being used for peak flow mitigation or due to a lack of a suitable site outlet, it is likely a computer model will be used. If the infiltration basin was modeled using a computer model, the volume infiltrated can be obtained from the model.

If the infiltration feature is being solely used to treat the Water Quality Volume, the following procedure can be followed once the Water Quality Volume is calculated (assuming a computer model was not used). If there is offsite flow going into the infiltration feature, it must also be considered.

$$V_i = A_b * k * T_c \quad \text{[Equation 9.1]}$$

Where:

V_i = volume of water infiltrated, ft³

A_b = basin or swale bottom surface area, ft²

k = infiltration rate of existing underlying soil, ft/hr

T_c = time of concentration to feature, hr

If the volume of water infiltrated is greater than or equal to the WQ_v , no further calculations for water quality are required. If the volume of water infiltrated is less than the WQ_v , additional calculations are required to determine how much above ground storage volume is required in the feature and if the feature will fully drain within 72 hours. If the infiltration feature is a swale requiring above ground storage, the swale will be modeled as a basin.

Based on NRCS hydrograph analyses performed by others, the effective filling time for most infiltration basins will generally be less than two hours. Using a max filling time of two hours results in the equation below:

$$V_b = WQ_v - (T_f * k * A_b) \quad \text{[Equation 9.2]}$$

Where:

V_b = basin volume, ft³

T_f = 2 hr

k = infiltration rate of existing underlying soil, ft/hr

A_b = basin or swale bottom surface area, ft²

Check to ensure the basin will fully drain within 72 hours:

$$T_d = \frac{WQ_v}{A_b} * k \quad \text{[Equation 9.3]}$$

Where:

T_d = time to drain, hr

9.05 Infiltration Seeding

Infiltration basins and swales will be planted with the Native Grass Seed Mix found in the Appendix. A plant growth layer should not be included because the infiltration rate of the soil will be affected. The Native Grass Seed Mix was designed to include seeds that require less organic material.

10.0 HYDRODYNAMIC SEPARATORS

10.01 Hydrodynamic Separators Overview

There are many different types of proprietary post-construction structural stormwater measures in use, such as hydrodynamic separators, gravity oil-grit separators, and catch basin inserts. For INDOT projects, typically only hydrodynamic separators should be proposed.

Hydrodynamic separators, also referred to as swirl concentrators and other proprietary names, are modifications of traditional oil-grit separators and are a type of flow-through device. These devices use a swirl or vortex to remove solids and trash via gravity from stormwater run-off. Although swirl concentration is most common, some devices use circular screening or cylindrical sedimentation.

10.02 Hydrodynamic Separators Applications

The small size of hydrodynamic separators makes them ideal when right-of-way is very limited and are often used in urban areas. However, they generally are part of a storm sewer system, with inflow entering the unit through one pipe and exiting out of another pipe. If a hydrodynamic

separator is used in combination with another structural measure, it is ideal to install it upstream rather than downstream.

10.03 Hydrodynamic Separators Advantages and Limitations

The biggest advantage of a hydrodynamic separator is the small footprint. They are often the only feasible solution for removing TSS from run-off for projects in urban settings with storm sewer systems and limited right-of-way. Hydrodynamic separators can also be retrofitted into existing drainage systems.

Although very effective at removing TSS from run-off, hydrodynamic separators will only function if properly maintained. Frequent inspection and cleanout are required. The initial cost of hydrodynamic separators can be relatively high.

10.04 Hydrodynamic Separators Design

The Water Quality Treatment Rate is required for hydrodynamic separator design. Larger flows can be bypassed using diversion structures. Online and offline units are both acceptable depending on project constraints. The unit will be chosen from the most current list of approved units provided through the [Environmental Services Division Stormwater webpage](#). Adequate space for safe inspections and maintenance should be provided in the design.

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APPENDIX – SEED MIXES

NATIVE GRASS SEED MIX

Common Name	Botanical Name	Pure Live Seeds Oz/Acre
Common Milkweed	<i>Asclepias syriaca</i>	2
Frank's Sedge	<i>Carex frankii</i>	6
Spreading Oval Sedge	<i>Carex normalis</i>	6
Bottlebrush Sedge	<i>Carex lurida</i>	6
Awl-fruited Sedge	<i>Carex stipata</i>	6
Fox Sedge	<i>Carex vulpinoidea</i>	8
Common Rush	<i>Juncus effusus</i>	2
Canada Wild Rye	<i>Elymus canadensis</i>	36
Virginia Wild Rye	<i>Elymus virginicus</i>	36
Stiff Goldenrod	<i>Oligoneuron rigidum</i>	1
Switch Grass	<i>Panicum virgatum</i>	4
Little Bluestem	<i>Schizachyrium scoparium</i>	96
Woolgrass	<i>Scirpus cyperinus</i>	2
Reddish Bulrush	<i>Scirpus pendulus</i>	4
Prairie Cord Grass	<i>Spartina pectinata</i>	6
Common Spiderwort	<i>Tradescantia ohimensis</i>	2
Total		223

Cover Crop		Pure Live Seeds Oz/Acre
Common Oats	<i>Avena Sativa</i>	560

EMERGENT PLANT SEED MIX

Common Name	Botanical Name	Pure Live Seeds Oz/Acre
Common Water Plantain	<i>Alisma subcordatum</i>	1
Swamp Milkweed	<i>Asclepias incarnata</i>	2
River Bulrush	<i>Bolboschoenus fluviatilis</i>	2
Bluejoint Grass	<i>Calamagrostis canadensis</i>	3
Common Fox Sedge	<i>Carex stipata</i>	3
Fox sedge	<i>Carex vulpinoidea</i>	6
Blunt Spike Rush	<i>Eleocharis obtusa</i>	1
Great Spike Rush	<i>Eleocharis palustris</i>	1
Virginia Wild Rye	<i>Elymus virginicus</i>	16
Spotted Joe Pye Weed	<i>Eutrochium maculatum</i>	1
Fowl Manna Grass	<i>Glyceria striata</i>	3
Canadian Rush	<i>Juncus canadensis</i>	1
Common Rush	<i>Juncus effusus</i>	2
Rice Cut Grass	<i>Leersia oryzoides</i>	2
Chairmakers Rush	<i>Schoenoplectus pungens</i>	1
Softstem Bulrush	<i>Schoenoplectus tabernaemontani</i>	2
Dark Green Rush	<i>Scirpus atrovirens</i>	1
Wool Grass	<i>Scirpus cyperinus</i>	1
Red Bulrush	<i>Scirpus pendulus</i>	1
Wild senna	<i>Senna hebecarpa</i>	2
Common Bur Reed	<i>Sparganium eurycarpum</i>	4
Prairie Cord Grass	<i>Spartina pectinata</i>	3
New England Aster	<i>Symphyotrichum novae-angliae</i>	0.5
Blue vervain	<i>Verbena hastata</i>	1
Total		60.5

Cover Crop		Pure Live Seeds Oz/Acre
Common Oats	<i>Avena Sativa</i>	540

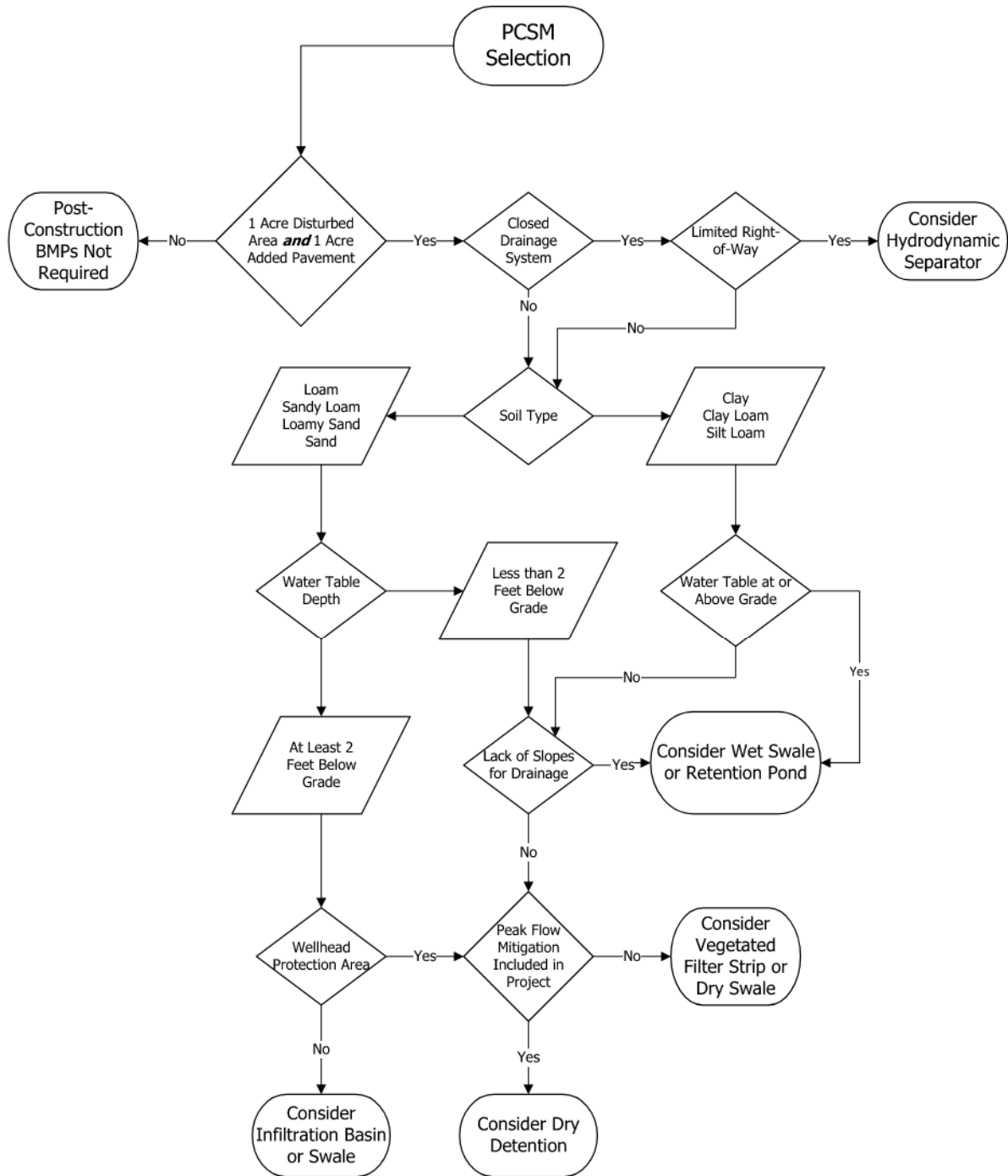
FIGURES

Structural Measures	Description	Pollutant Removal Mechanism	Priority
Dry Turf Grass Swale	A broad and shallow channel planted with grass. Fully drains between rainfall events.	Sedimentation, physical filtration, and biofiltration	1
Dry Native Grass Swale	A broad and shallow channel planted with dense specialized plants. Fully drains between rainfall events.	Sedimentation, physical filtration, and biofiltration	1
Filter Strip	A vegetated linear section of land. Also often referred to as a buffer strip.	Physical filtration, sorption, biofiltration	1
Dry Detention	An engineered pond or swale planted with grass. Fully drains between rainfall events. Includes an outlet structure to control flow.	Sedimentation, physical filtration, and biofiltration	1
Wet Swale	A broad and shallow channel planted with grass. Designed with a permanent pool and an elevated outlet structure.	Sedimentation, physical filtration, and biofiltration	2
Wet Retention Pond	Engineered basin designed to permanently store run-off. Designed with a permanent pool and an elevated outlet structure.	Sedimentation, physical filtration, and biofiltration	2
Infiltration Swale	A broad and shallow channel with permeable soil planted with grass. Designed to infiltrate run-off into the underlying soil.	Sedimentation, physical filtration, infiltration, sorption, and biofiltration	3
Infiltration Basin	An engineered basin with permeable soil planted with grass. Designed to infiltrate run-off into the underlying soil.	Sedimentation, physical filtration, infiltration, sorption, and biofiltration	3
Proprietary Device	Hydrodynamic separators.	Sedimentation and physical filtration	4*

*In urban areas where right-of-way is limited, hydrodynamic separators may be preferred.

INDOT PREFERRED POST-CONSTRUCTION STRUCTURAL MEASURES

FIGURE 3A



MEASURE SELECTION FLOWCHART

FIGURE 3B

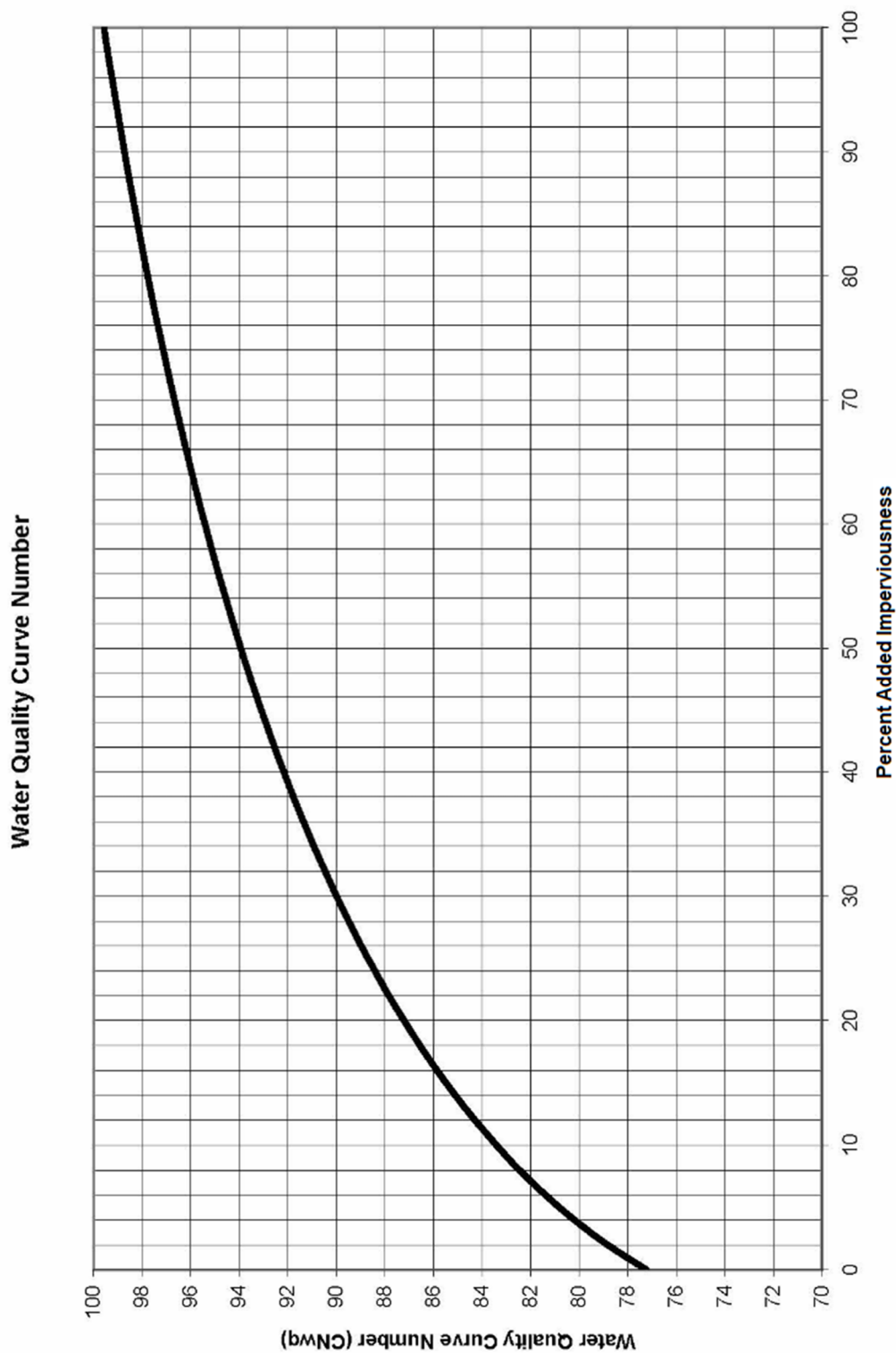
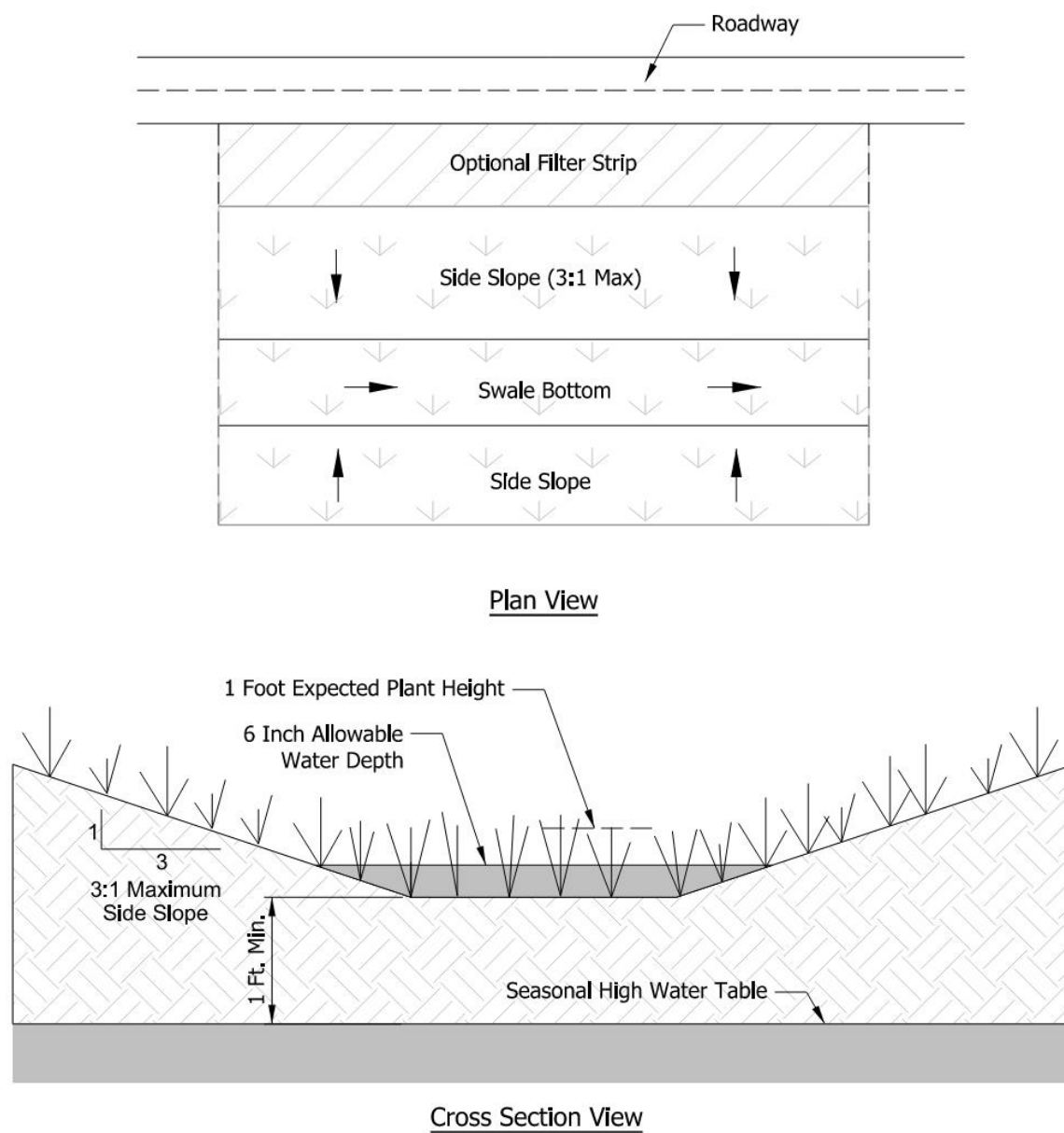
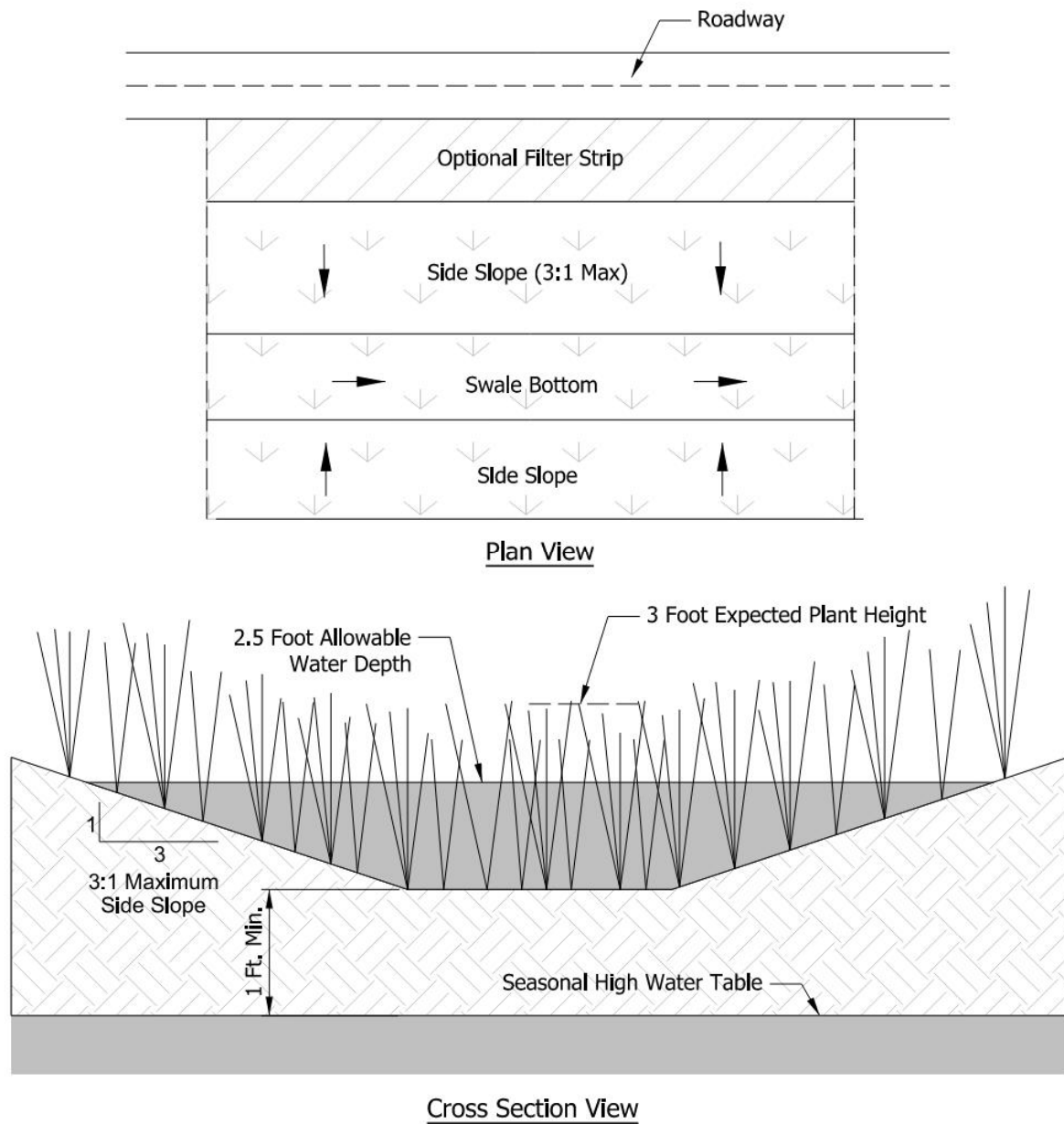


FIGURE 3C



DRY TURF GRASS SWALE DETAILS

FIGURE 4A



DRY NATIVE GRASS SWALE DETAILS

FIGURE 4B

Swale Type	Planting	Expected Plant Height	Maximum Allowable Water Depth at Water Quality Treatment Rate
Dry Turf Grass Swale	Turf Grass	1 foot	6 inches
Dry Native Grass Swale	Native Grass	3 feet	2.5 feet

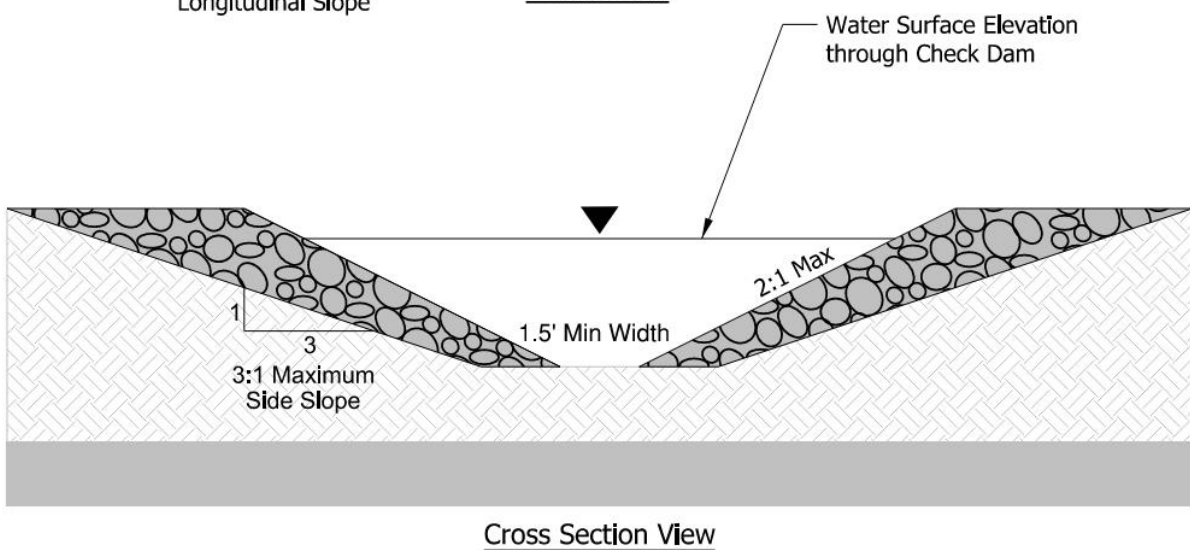
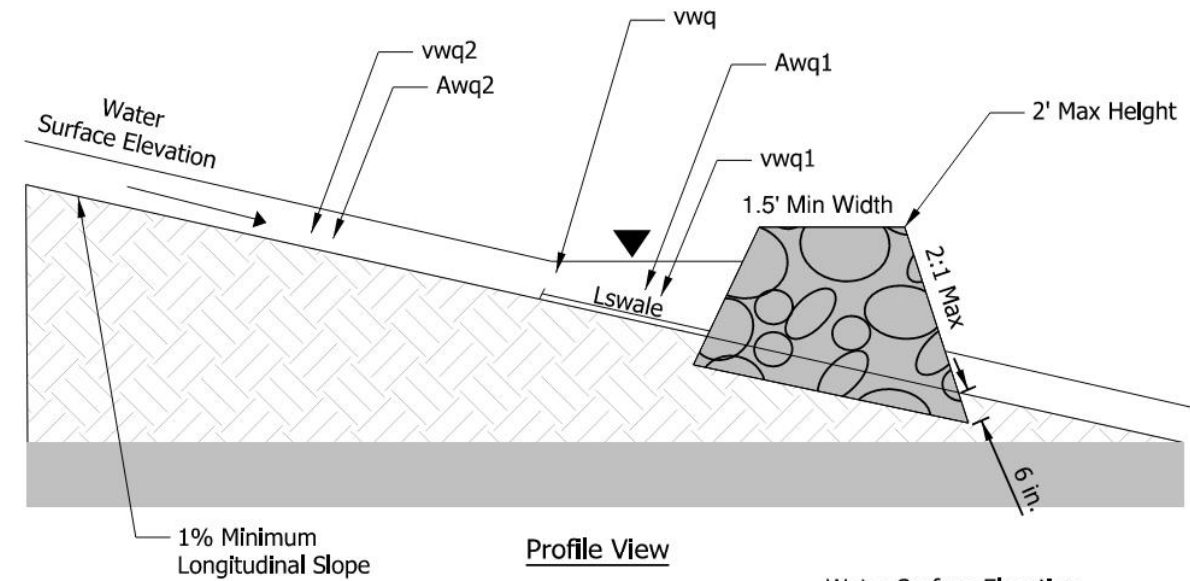
DRY SWALE ALLOWABLE WATER DEPTH

FIGURE 4C

Hydraulic Residence Time (minutes)	% Sediment Removal Achieved
9	80
8	75
7	70
6	65
5	60

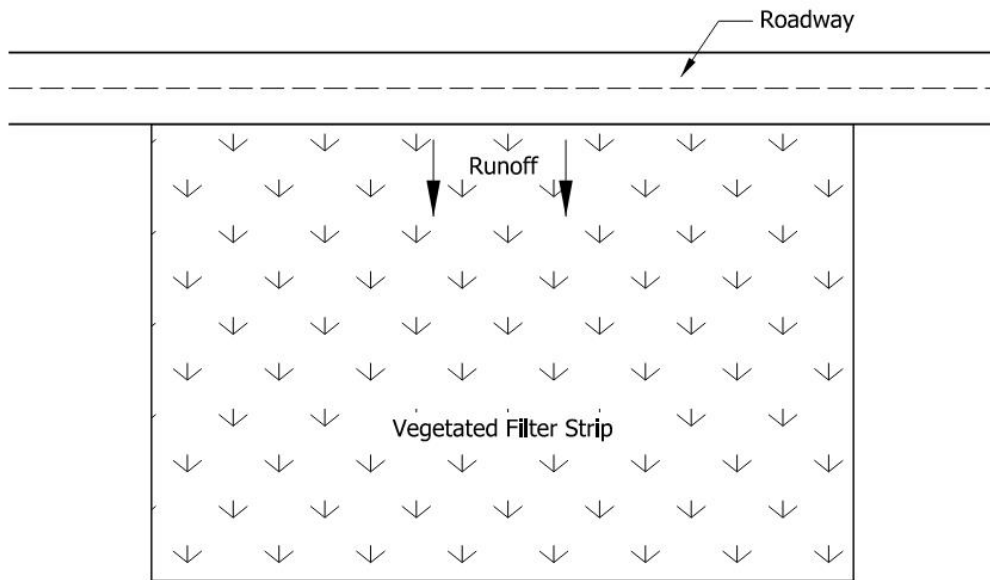
PERCENT SEDIMENT REMOVAL FOR DRY SWALES

FIGURE 4D

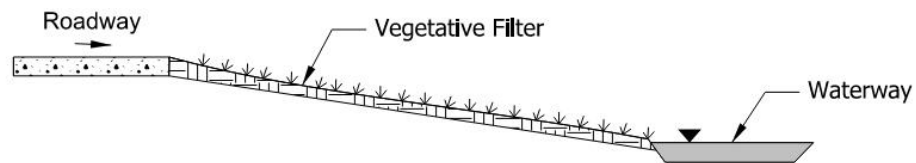


DRY SWALE CHECK DAM

FIGURE 4E



Plan View



Profile View

VEGETATED FILTER STRIP DETAILS

FIGURE 5A

Vegetated Filter Strip Length
Drainage Area Soil: Sand HSG: A

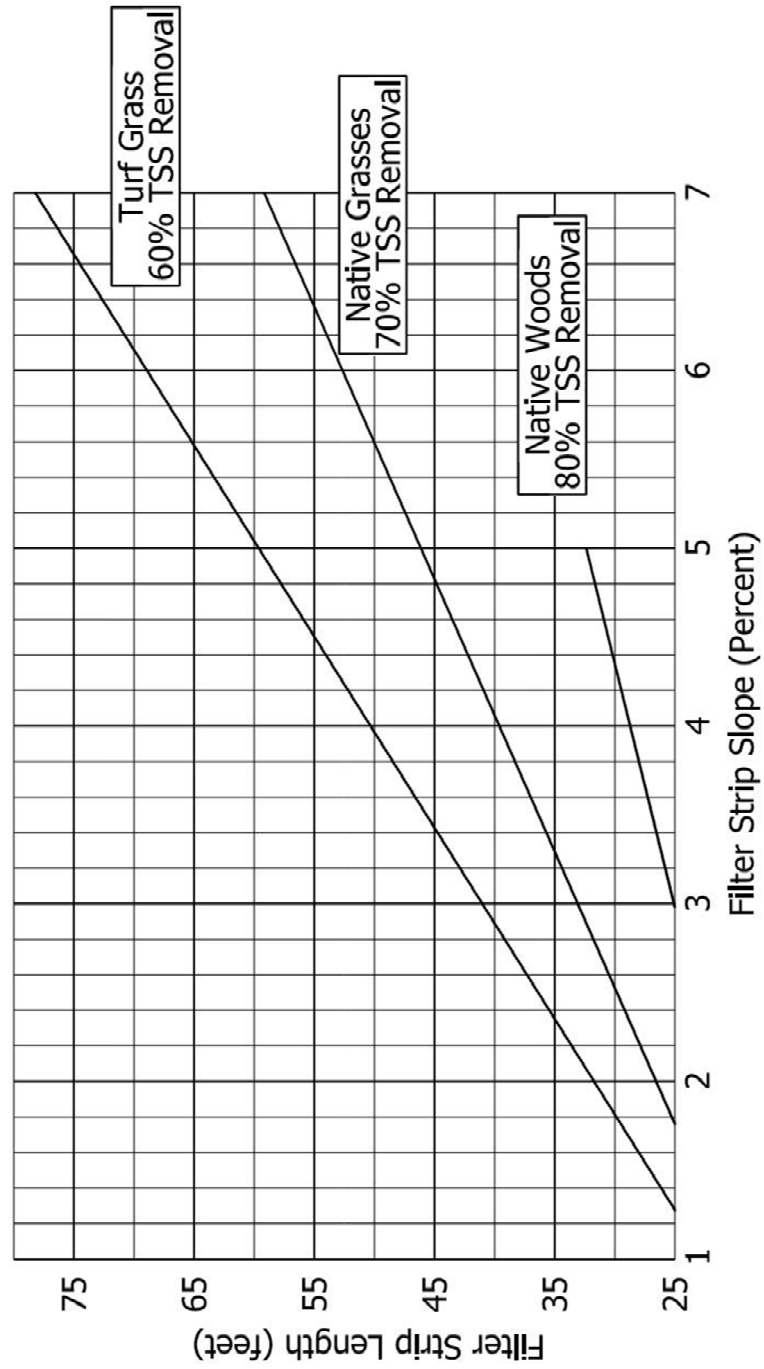


FIGURE 5B

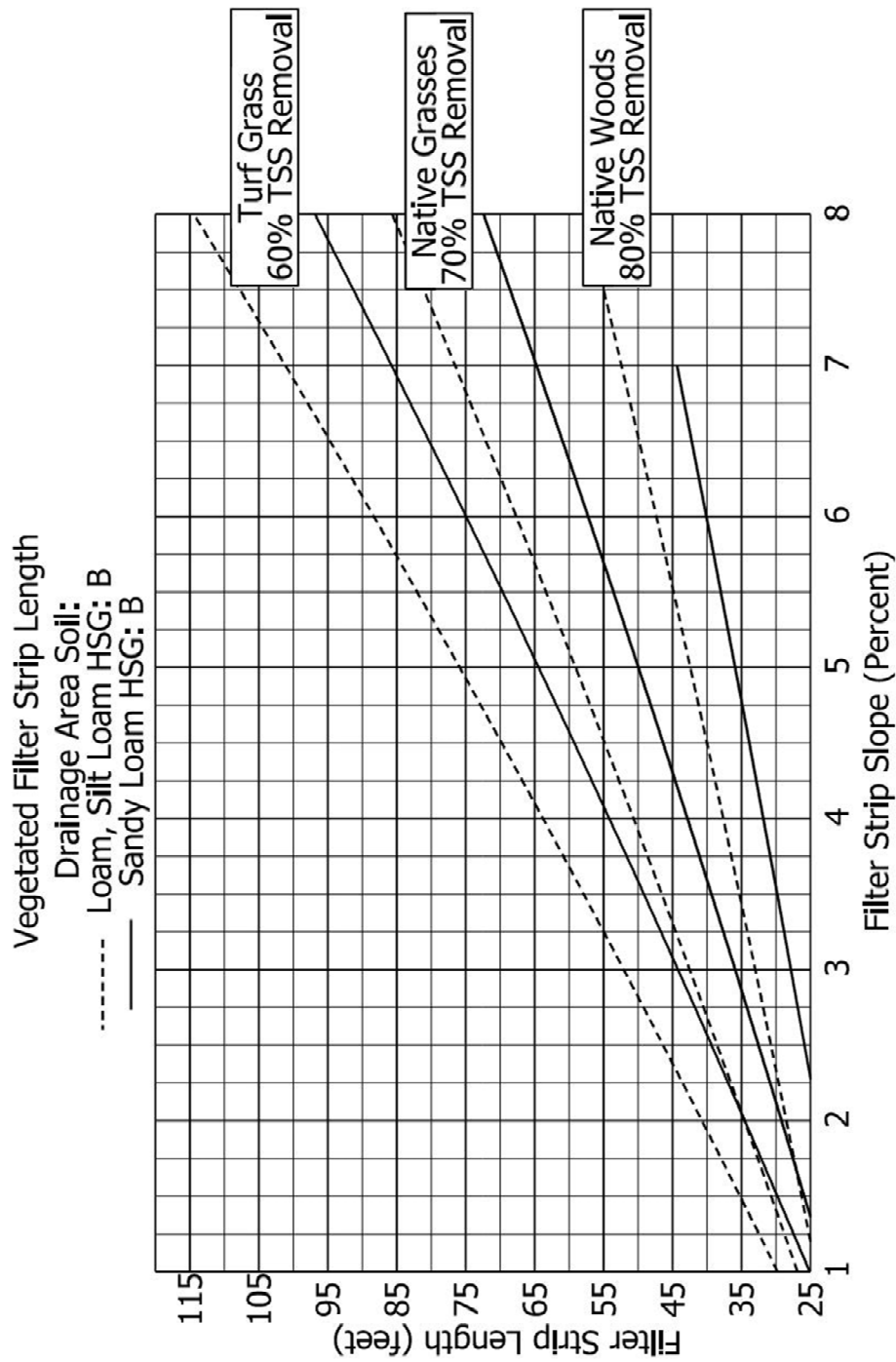


FIGURE 5C

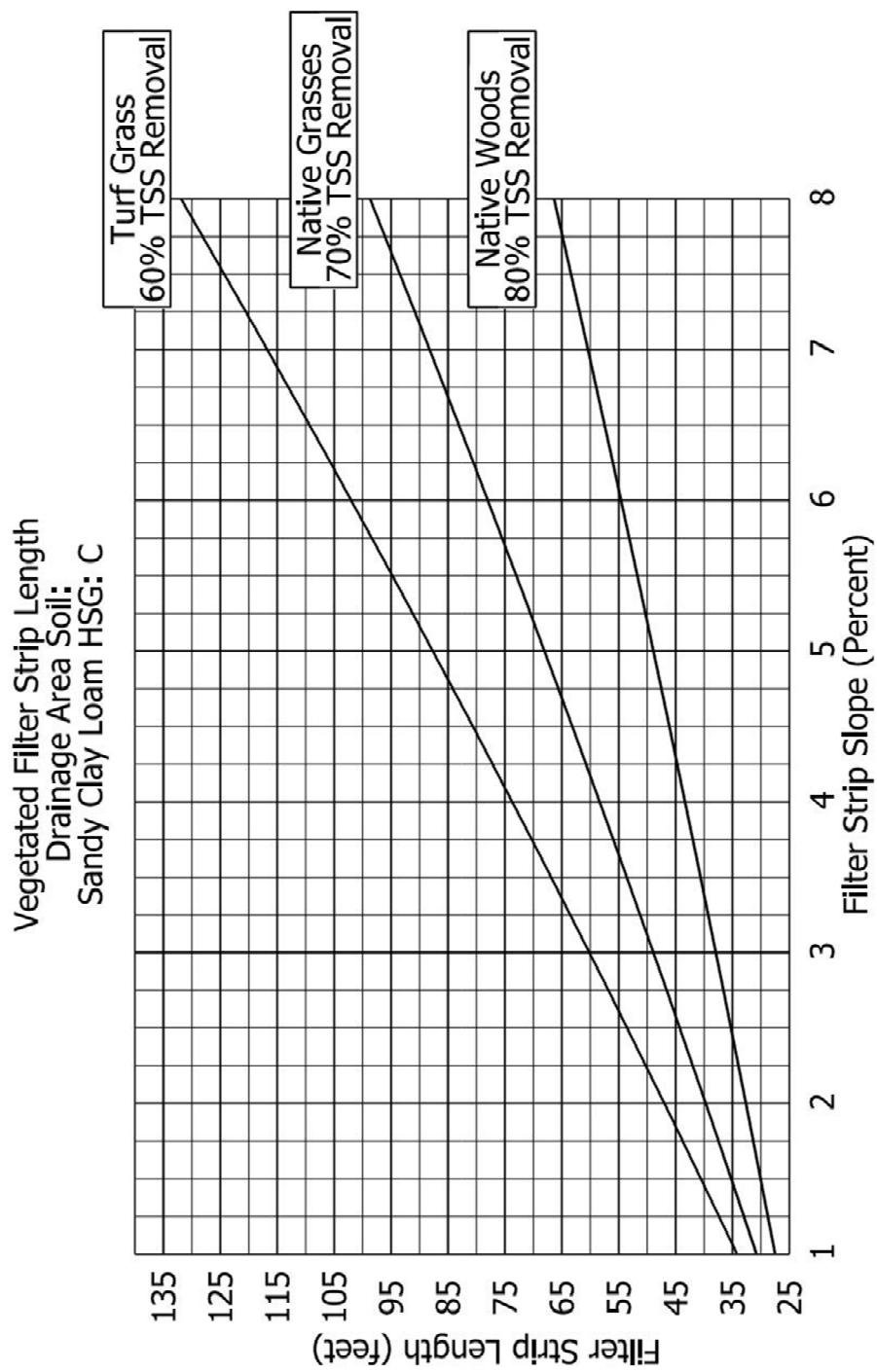


FIGURE 5D

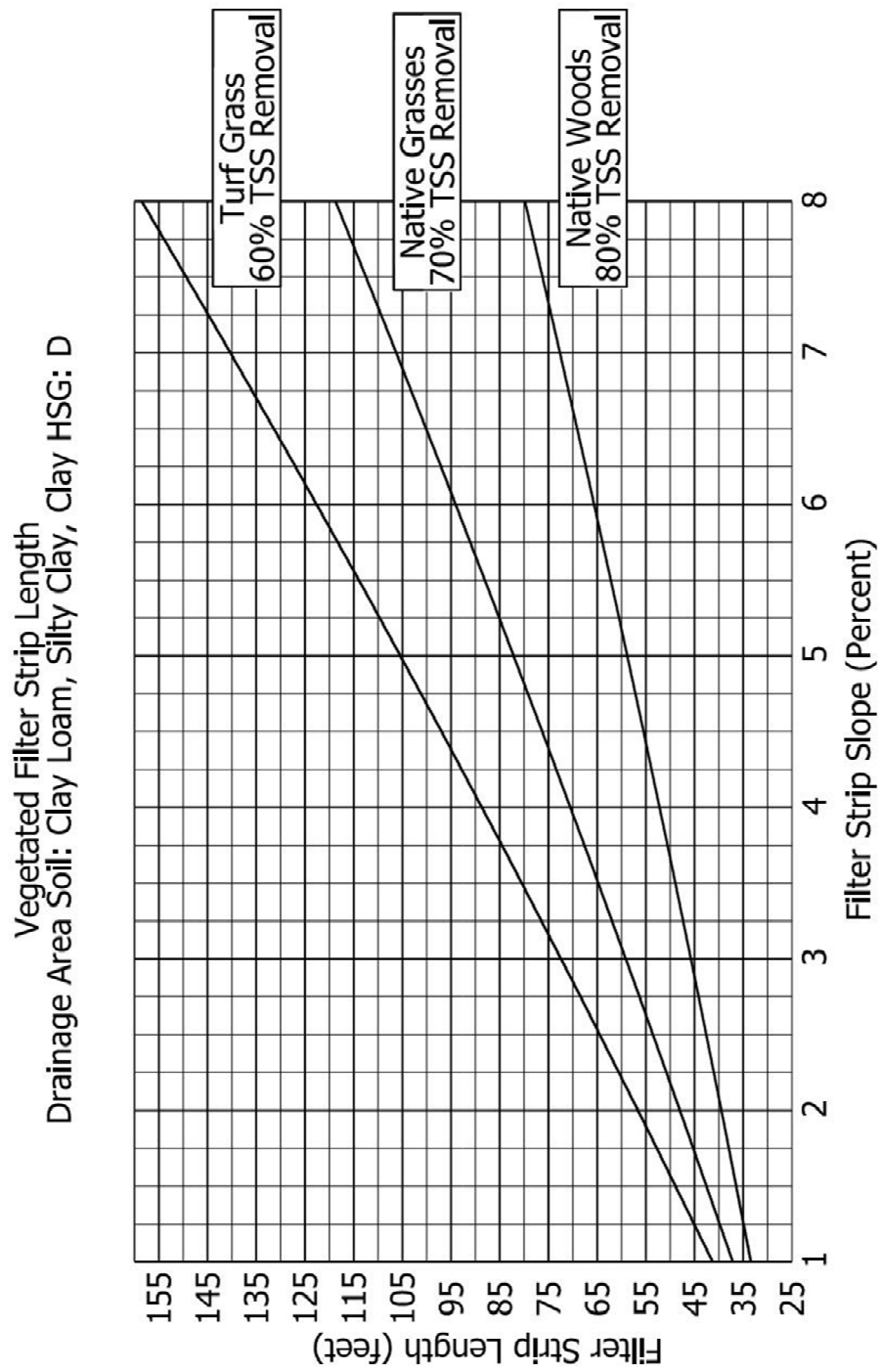
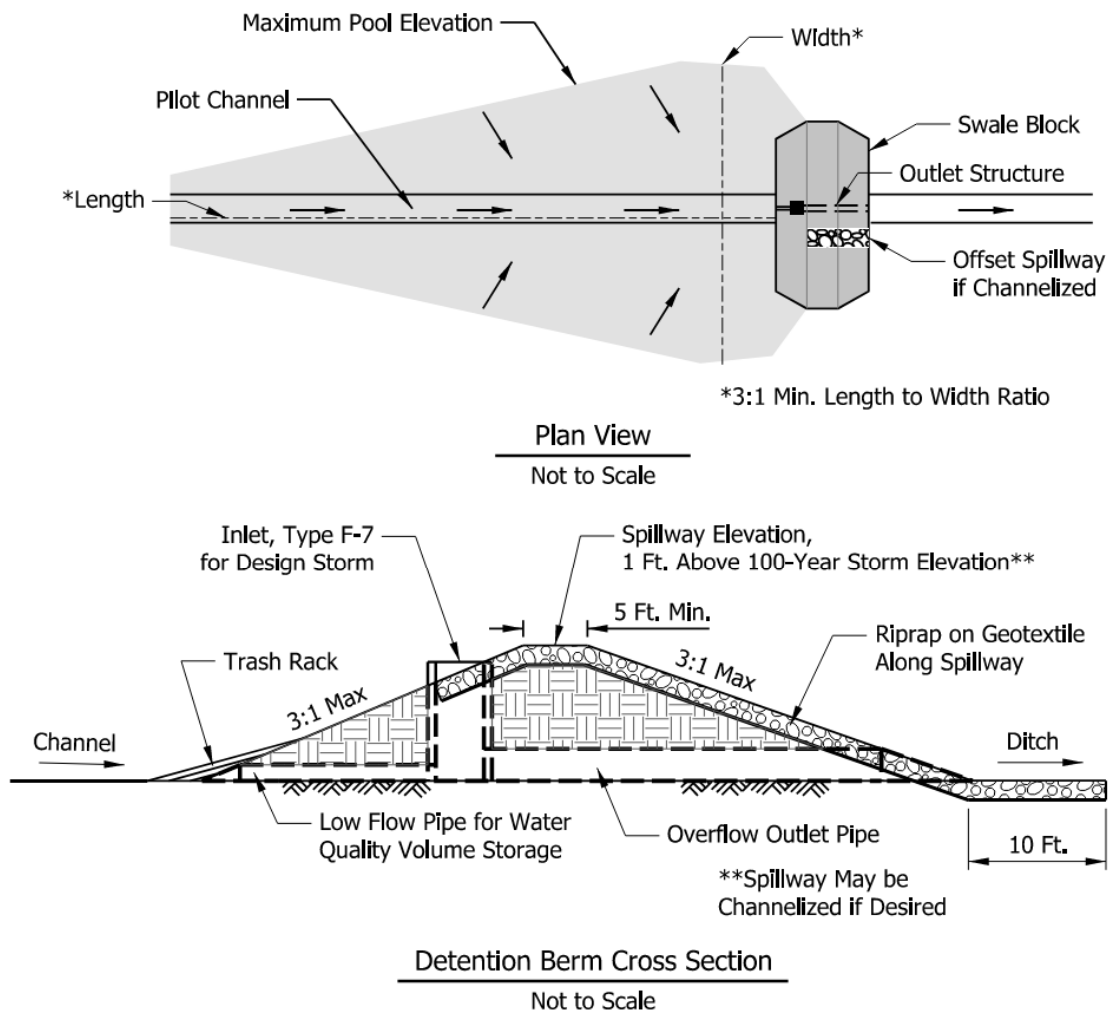
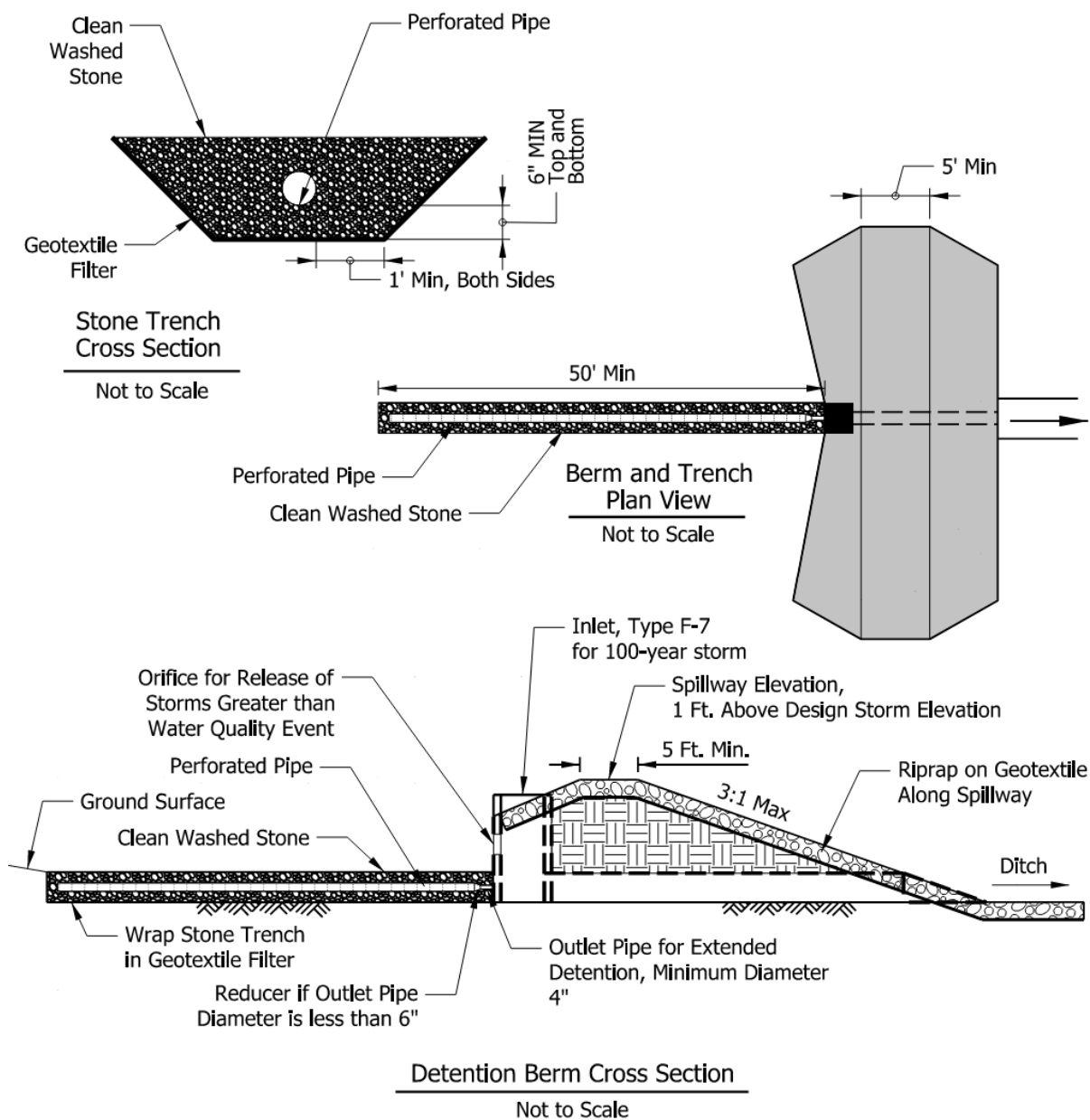


FIGURE 5E



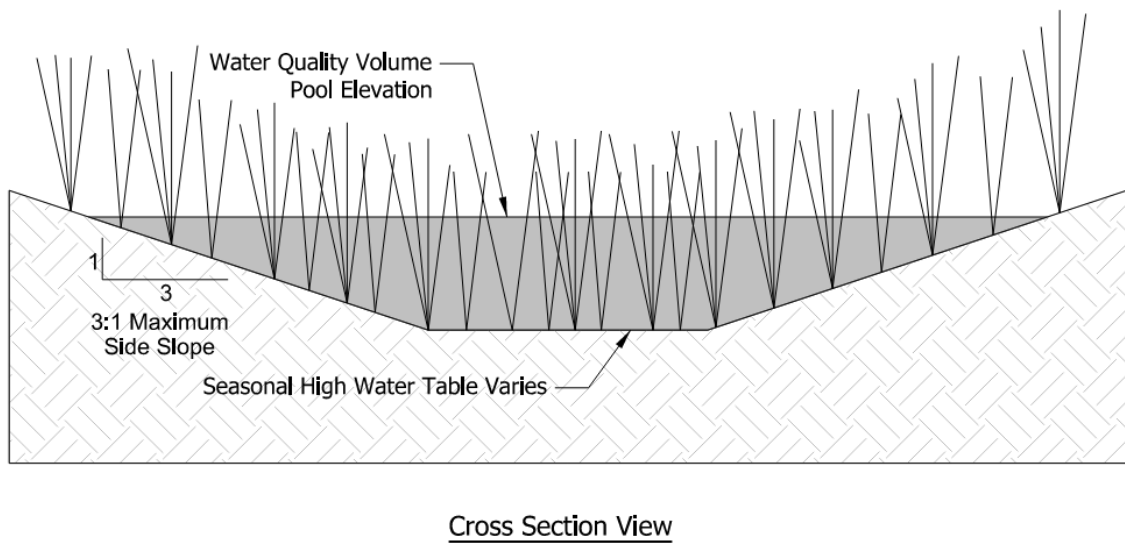
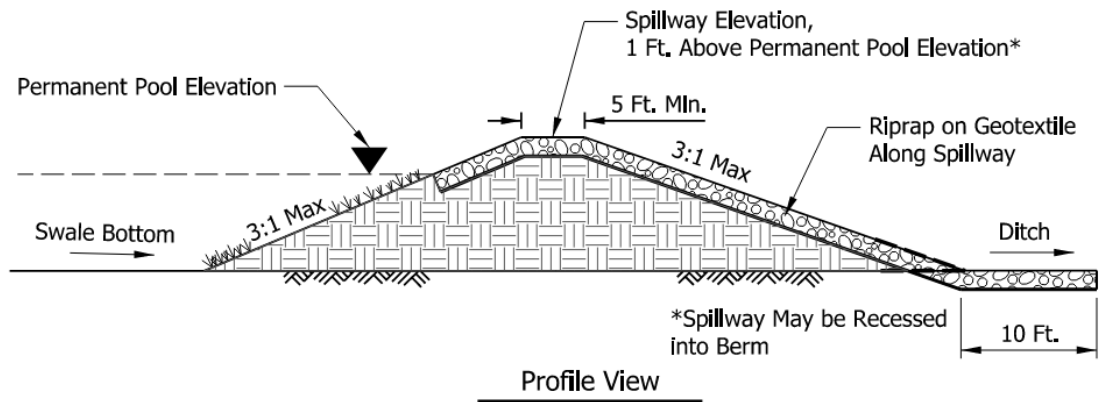
DRY DETENTION DETAILS

FIGURE 6A



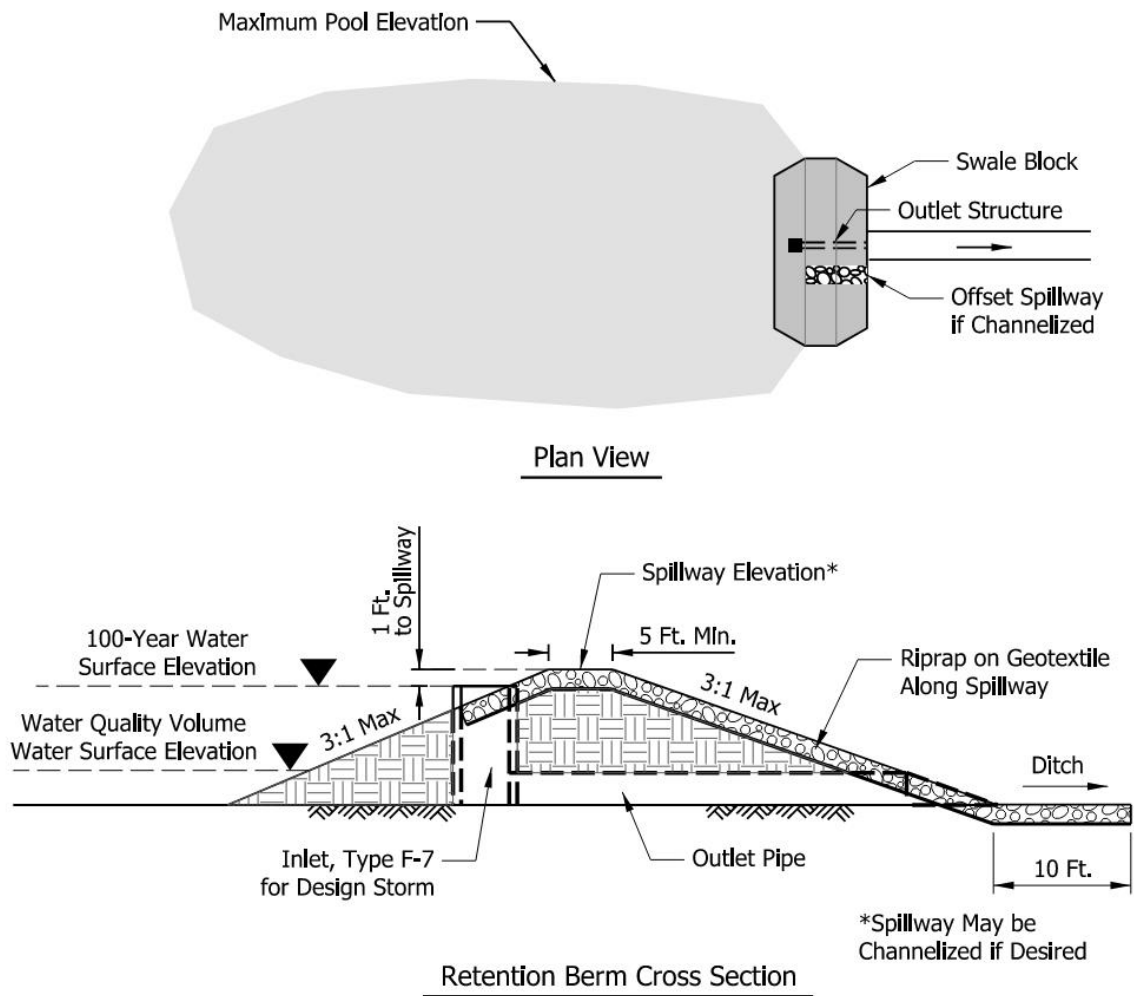
DRY DETENTION WITH UNDERDRAIN DETAILS

FIGURE 6B



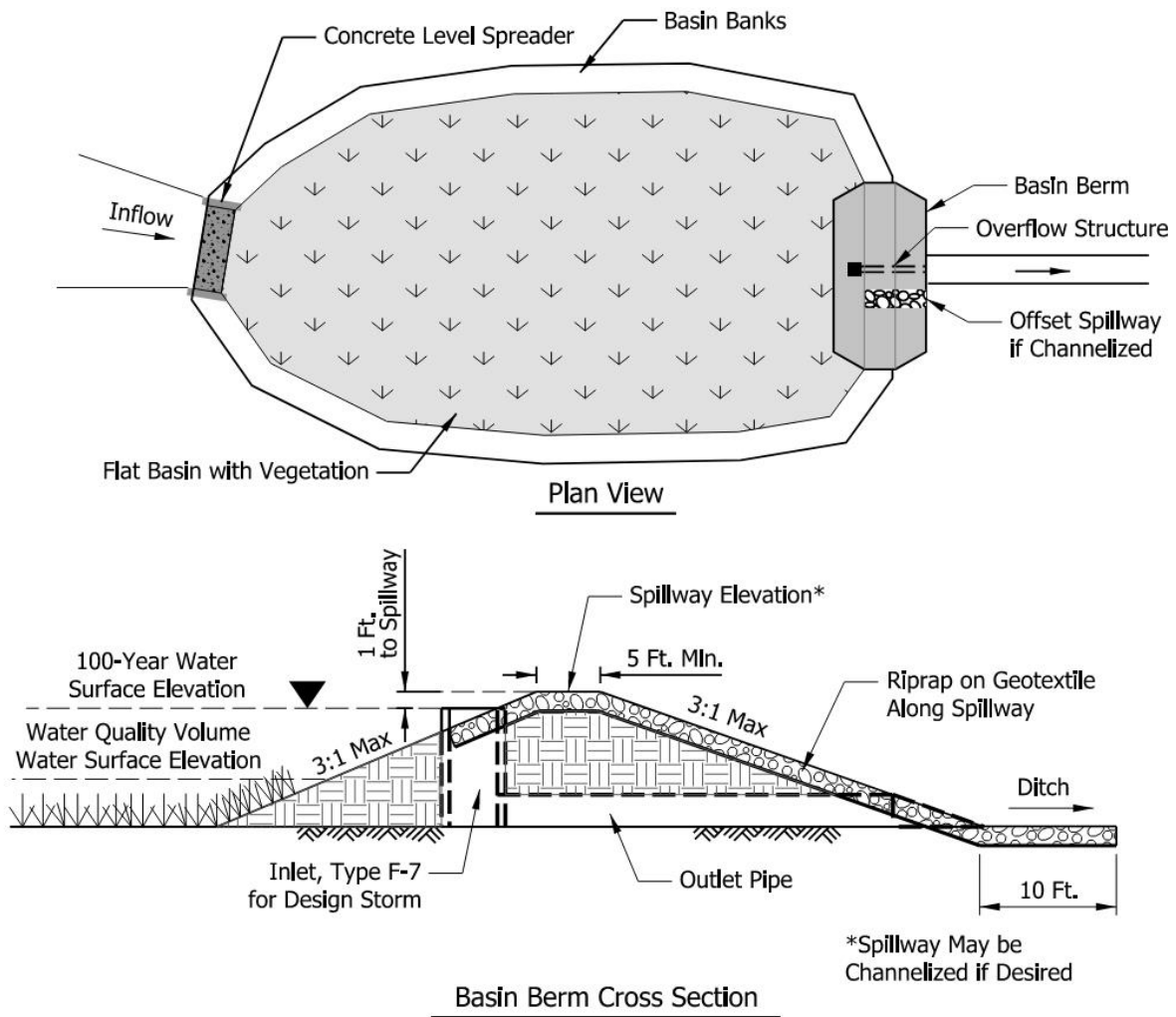
WET SWALE DETAILS

FIGURE 7A



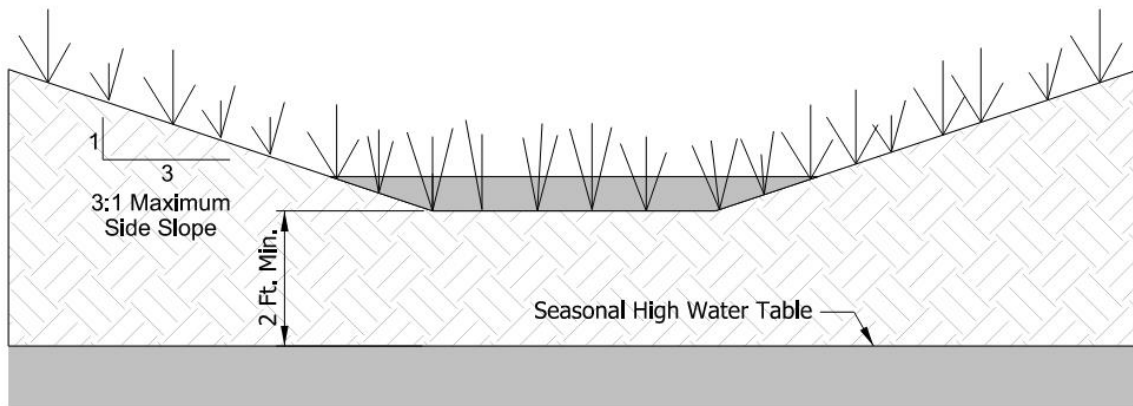
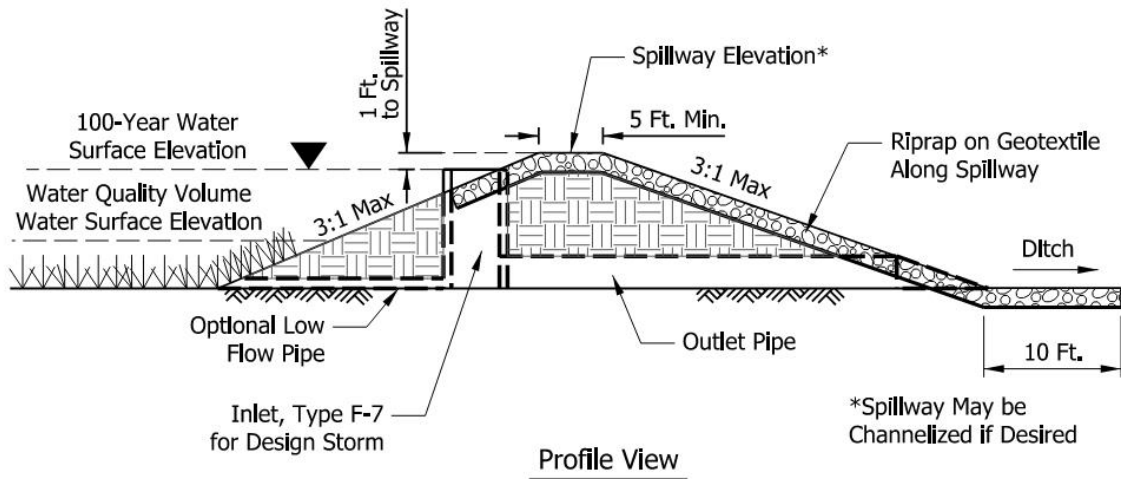
WET RETENTION POND DETAILS

FIGURE 8A



INFILTRATION BASIN DETAILS

FIGURE 9A



INFILTRATION SWALE DETAILS

FIGURE 9B